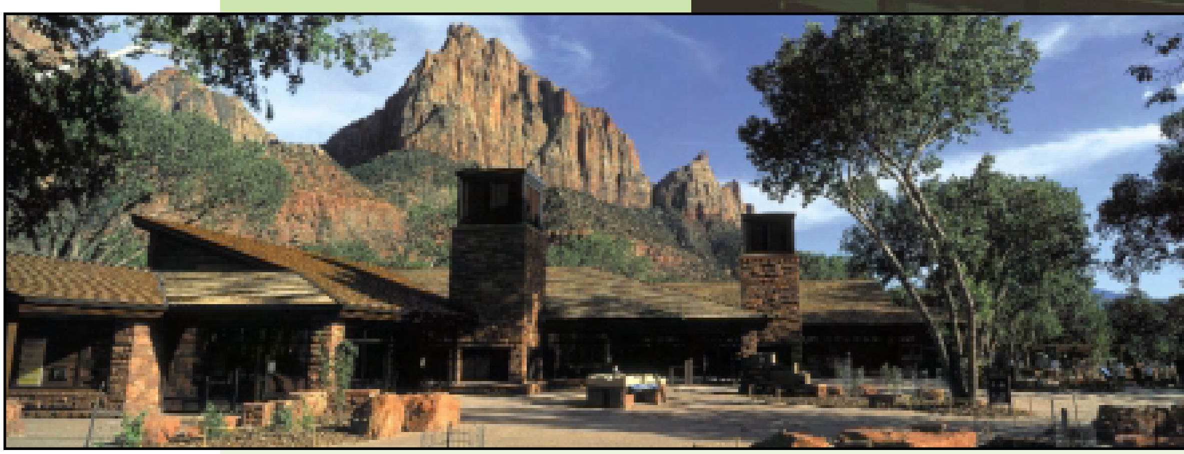
The Business Case for

SUSTAINABLE DESIGN IN FEDERAL FACILITIES

RESOURCE DOCUMENT



FEDERAL ENERGY MANAGEMENT PROGRAM

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

The Business Case for

SUSTAINABLE DESIGN IN FEDERAL FACILITIES

We at the Department of Energy believe there can be a sound business case for the use of sustainable design options, and we encourage all Federal agencies to incorporate these options whenever possible.

– David Garman

Assistant Secretary

Office of Energy Efficiency and Renewable Energy

U. S. Department of Energy

The Federal government has many leaders in this field already, and together we can demonstrate that a sustainable building is healthier, more environmentally sound, operationally and economically viable, and the way we should be doing business.

– John L. Howard, Jr.,

Federal Environmental Executive

October 2003

On the cover: National Institutes of Health, Louis Stokes Laboratories/Building 50, Bethesda, MD
Sandia National Laboratories' Process and Environmental Technology Laboratory, Albuquerque, NM
Zion National Park Visitors Center, Springdale, UT

Preface

"Sustainable design" is becoming a mainstream movement in the U.S. architecture and construction industry, and U.S. government agencies have been both joining that movement and leading the way. In the summer of 2001, the U.S. Department of Energy's Federal Energy Management Program (FEMP) and the U.S. Navy initiated the Interagency Sustainability Working Group as a forum for Federal agency representatives located in the Washington, D.C., area to share sustainable design experiences and information. The government members of this group include:

- Coast Guard
- Department of Agriculture
- Department of Commerce
  - National Oceanic and Atmospheric Administration
- Department of Defense
  - Department of the Air Force
  - Department of the Army; Army Corps of Engineers; Army Environmental Center
  - Department of the Navy; Naval Facilities Engineering Command
- Department of Energy
  - Lawrence Berkeley National Laboratory
  - National Renewable Energy Laboratory
  - Oak Ridge National Laboratory
  - Pacific Northwest National Laboratory
- Department of the Interior
  - Fish and Wildlife Service
  - National Park Service
- Department of State
- Environmental Protection Agency
- Executive Office of the President
  - Office of the Federal Environmental Executive
  - Office of Management and Budget
  - White House Task Force on Waste Prevention and Recycling
- General Accounting Office
- General Services Administration
- Indian Health Service
- National Aeronautics and Space Administration
- Postal Service
- State of California; State and Consumer Services Agency
- Tennessee Valley Authority

The group expressed a strong interest in communicating the business case for sustainable design. In response, FEMP initiated the effort documented in this report, which focuses on providing solid arguments, supported by defensible data, to further justify the application of sustainable design principles in Federal agency construction projects. Sustainable design is a natural extension of FEMP's established role as an energy-efficiency, renewable-energy, and water-efficiency advocate in the Federal sector.

Although the analysis in this document was targeted toward U.S. government facilities, the findings also have relevance to private-sector architects and engineers, developers and contractors, and building owners. In a recent survey conducted by the U.S. Green Building Council, members of the Council said that better understanding the costs and benefits of sustainable design was a high priority. Architectural and engineering firms that promote sustainable design have also expressed a need to communicate the business case.

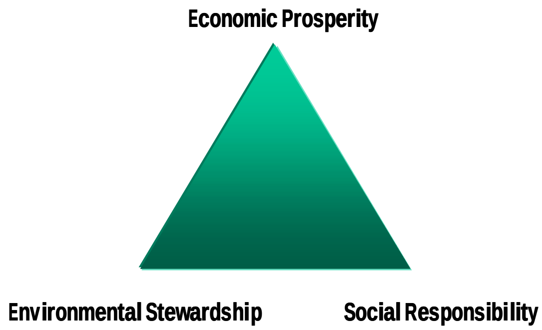
This document is a technical resource report containing cost information, research results, case studies, and other quantitative and qualitative information pertaining to the business case for sustainable design. It serves as a companion document to another shorter publication that summarizes the business case for sustainable design and construction. Both documents can be found on the FEMP website: http://www.eere.energy.gov/femp.

Executive Summary

What is Sustainable Design and Construction?

Sustainability means choosing "paths of social, economic, and political progress that meet the needs of the present without compromising the ability of future generations to meet their own needs."[i] The concept of sustainability includes three key goals, sometimes called the "triple bottom line:"

- **Environmental stewardship –** Protecting air, water, land, and ecosystems and conserving resources, including fossil fuels, thus preserving the Earth's resources for future generations
- **Social responsibility –** Improving the quality of life for individuals, communities, and society as a whole
- **Economic prosperity –** Reducing costs, adding value, and creating economic opportunity for individuals, organizations, and communities.



When designers apply these concepts to architecture, they take a holistic look at all aspects of the design to minimize the use of energy, materials, and natural resources, as well as the environmental impacts of the building and site. Designers also try to maximize the quality of life inside the building and its positive effects on the surrounding community. The principles of sustainable building design and construction include optimizing site potential, minimizing energy consumption, protecting and conserving water, using environmentally preferable products, enhancing indoor environmental quality, and optimizing operational and maintenance practices.[ii]

The Business Case for Sustainable Design and Construction

Many Federal designers and planners embrace the goals of environmental stewardship and social responsibility, but capital budget constraints often stand in the way of smart design choices. Federal managers need hard facts and figures to help articulate the "business case" for sustainable design. Without clear information about the lifecycle costs and other benefits of design alternatives, Federal decision-makers are likely to continue favoring traditional design choices.

This document serves as a resource for people working on Federal and private-sector sustainable construction projects. By providing significant financial evidence from research and case studies, this document can help Federal designers make the case that sustainable design is a smart business choice.

Sustainable Design and Construction in the Federal Sector

The Federal government has been leading by example in the field of sustainable design. Many Federal agencies have developed policies to promote sustainable design concepts, and their buildings are achieving prestigious silver and gold ratings from the Leadership for Energy and Environmental Design (LEED™) rating system developed by the U.S. Green Building Council.[iii] Federal laws and Executive Orders have established goals and provide guidance to building designers in the Federal sector; for example, government agencies are required to apply sustainable design principles and install energy and water conservation measures that have a payback period of less than 10 years. Laws and Executive Orders also mandate that Federal managers use lifecycle cost analysis for all projects. This approach supports the use of many sustainable design features because the annual cost savings from these features over their lifetimes can offset their sometimes-higher first costs. However, because capital budgets are usually preset for Federal construction projects, government-building designers sometimes find it difficult to increase the capital budget to include the incremental first costs of some sustainable design features. Nevertheless, Federal agencies have found many creative ways to stay within their capital budgets while making their buildings "green." In fact, sustainable design does not have to increase the cost of constructing a facility, and in some cases, may actually lower first costs, as well as operating costs.

The Benefits of Sustainable Design and Construction

A growing body of evidence shows that sustainable buildings reap rewards for building owners and operators, building occupants, and society. The business case for sustainable design can be described using the "triple bottom line" framework. The three categories of benefits are shown in the box below.

At Zion National Park Visitors Center in Utah, designers moved exhibit space outdoors and introduced natural cooling and lighting. The building cost 30% less to build and reduces energy cost by 70% compared with a conventional facility that just meets code.

Economic Benefits

- Lower (or equal) first costs
- Decreased annual energy costs
- Reduced annual water costs
- Lower maintenance and repair costs
- Better productivity and less absenteeism
- Indirect economic benefits to the building owner, e.g., lower risk, ease of siting, and improved image
- Economic benefits to society, e.g., decreased environmental damage costs. lower infrastructure costs, and local economic growth

Social Benefits

- Health, comfort, and well-being of building occupants
- Building safety and security
- Commmunity and societal benefits

Environmental Benefits

- Lower air pollutant emissions
- Reduced solid-waste generation
- Decreased use of natural resources
- Lower ecosystem impacts

Economic Benefits

Economic benefits of sustainable design can include both capital and operating cost savings, as well as benefits, such as productivity improvements and lower permitting costs, derived indirectly from the very environmental and social benefits that sustainable buildings provide. To realize the full benefits, sustainable design must begin at the conceptual stage of a project and should be developed using an interdisciplinary team that examines integration of, and tradeoffs among, design features. When the team chooses to include sustainable features, often they can downsize or eliminate other equipment, resulting in *lower (or equal) first costs* for the sustainable design. Renovating older buildings, eliminating unnecessary features, avoiding structural over-design and construction waste, and decreasing the size of site infrastructure such as parking lots, roads, and sewers can also reduce first costs while providing environmental and social benefits. Some sustainable features, such as recycled carpet, concrete with fly ash, and no-water urinals, can cost less than their traditional counterparts.

Sustainable design also reduces annual operating costs. Case studies show that energy use can be reduced by as much as 70% by incorporating energy-efficient and renewable energy systems, with payback periods below 10 years.[iv] Water-saving devices such as low-flow faucets and showerheads and no-water urinals can reduce water consumption significantly (e.g., from 2.5 gallons per minute to 1.0 gallons per minute for low-flow faucets). Payback periods for these devices are typically short – from immediate for no-water urinals to less than 3 years for low-flow showerheads.

When designers of the Pennsylvania Department of Environmental Protection's Cambria Office Building first proposed an upgrade to triple-glazed, double low-e windows, the developer balked at the $15,000 increase in cost. However, he was won over when the designers were able to demonstrate that the upgrade would allow them to eliminate the perimeter heating zone for a savings of $15,000, downsize the heat pumps for another $10,000 savings, and increase floor space because of the smaller equipment and ducts for a gain of $5,000 in rent.

Laboratories are energy-intensive. The Process and Environmental Technology Laboratory at Sandia National Laboratories in New Mexico spent just 4% more in their capital budget for energy-efficient technologies, saving enough energy to pay off that investment in about three years, with continued savings for many years to come.

Another key tenet of sustainable design is increased durability and ease of maintenance. Concrete with fly ash is more durable than normal concrete, potentially decreasing future repair costs; and low-emitting (low-VOC) paint is also reported to be more durable than regular latex paint. Sustainable landscaping typically decreases maintenance costs (e.g., for lawn care, fertilizers, and irrigation) and has a short payback period (e.g., less than a year).

Use of raised floors and underfloor HVAC and telecommunications systems, as well as moveable wall partitions, can reduce the churn cost (cost to reconfigure space and move people within the building) by over $2000 per person moved. Given that an estimated 27% of people in a government building move each year, reducing churn costs can save over $1 million/yr in a large building with 2000 workstations.

Personnel costs in the U.S government far exceed construction, energy, or other annual costs. Sustainable buildings potentially lower absenteeism and increase productivity. A recent study estimated potential annual cost savings on the order of $25,000 per 100 employees resulting from a one-time investment in better ventilation systems of $8000 per 100 employees.[v] Another study estimated that the value of improved productivity (including lower absenteeism) of office workers could be as high as $160 billion nationwide.[vi]

Other indirect and longer-term economic benefits to the building owner include the following:

- **Better worker retention and recruitment.** The environmental image associated with an employer that builds a sustainable building and the improved indoor environment within the building may reduce turnover, improve morale, and help create a more positive commitment to the employer, as well as lower recruiting and training costs.
- **Lower cost of dealing with complaints**. A recent study showed that increased occupant comfort could result in a 12% decrease in labor costs for responding to complaints.[vii]
- **Decreased risk, liability, and insurance rates**. Some insurance companies offer lower rates for buildings with energy-efficiency and other sustainable features. Sustainable buildings also reduce the risk of liability from sick building syndrome and natural disasters.
- **Greater building longevity.** If buildings do not have to be demolished and replaced, the government's construction costs will be lower over the long run. Some strategies for prolonging building use include selecting durable materials, designing photovoltaic-ready roofs, building foundations that will accept additional floors later, and designing with classic and regionally appropriate styles.

When workers at the West Bend Mutual Insurance Company moved into their new building with personal controls for their workstations and other sustainable features, productivity increased 16%.

Some insurance companies offer insurance premium credits when the insured implement selected energy-savings strategies. For example, the nation's largest professional liability insurer – DPIC – offers 10% credits for firms that practice commissioning, and Hanover Insurance offered 10% credits for earth-sheltered or solar buildings on the basis that their fuel-based heating system has fewer operating hours, thus reducing fire risks.

A study of the new headquarters for the Herman Miller furniture company indicates that the new sustainable building had positive impacts on occupants' well-being, job satisfaction, feelings of belonging, and other aspects of work life that affect individual job performance. Productivity measured by the company's own total quality metrics increased when employees moved into the new space,

Picture: Kahujku Ranch, Hawaii

Although some would say that something like a unique ecosystem is "priceless," certain groups within American society do place economic value on, and are willing to pay for, environmental and natural resources. For instance, the Nature Conservancy is planning to invest $1 billion to save 200 of what they call the world's "Last Great Places."

- **Better resale value.** In 1998, the U.S. General Services Administration sold over 1500 properties at a total selling price of about $250 million. Investing in sustainable design features can considerably increase a property's resale value because it lowers annual costs and makes a building more profitable for the new owner.
- **Ease of siting.** Gaining early support from a community can greatly speed up approvals for a project. For example, the developers of Central Market, a store in the town of Poulsbo, Washington, say that their decision to enhance an onsite wetland and offer it to the city as a park not only reduced maintenance costs but also avoided project delays by generating strong community support.[viii]

Benefits of sustainable design accrue not only to the building owner, but also to society at large. For example, energy-efficiency measures reduce public costs from pollution damages. Studies estimate the costs to society of air pollutant emissions to be $100 to $7500 per metric ton for sulfur dioxide (SO_2), $2300 to $11,000 per metric ton for nitrogen oxides (NO_x), and $6 to $11 per metric ton for carbon dioxide (CO_2).[ix] Sustainable development may also reduce taxpayer's costs for municipal infrastructure (e.g., decreased need for landfills, water/sewage treatment plants, and roads) and may foster regional economic growth through emerging businesses associated with sustainable buildings.

Social Benefits

Sustainable buildings can improve the health and well-being of building occupants. Sick building syndrome symptoms can be reduced by increased ventilation, personal control over thermal conditions, improvements in ventilation system maintenance and cleaning, reduced use of pesticides, and good maintenance. Studies also show that building features such as stable and comfortable temperature, operable windows, views out, usable controls and interfaces, and places to go at break time have positive psychological and social benefits. The benefits include reduced stress, improved emotional functioning, increased communication, and an improved sense of belonging.

Certain features of sustainable buildings can also foster occupant safety and security. For instance, improving control of building air distribution systems – including periodic calibration of sensors, adjustment of dampers, and other system maintenance – is essential for rapid response to an emergency and contributes to energy-efficient operation under normal conditions. Tighter building envelopes have the dual benefits of reducing energy losses from infiltration and making it easier to pressurize a building, thus reducing entry of an airborne hazard that was released outside.

> "In the process of renovating the Pentagon, we've found that several of the force protection measures we are taking to protect the Pentagon against terrorist attacks are complementary to our sustainable construction efforts. These are all examples of building security and energy efficiency working hand in hand."
>
> Teresa Pohlman, Special Assistant for Sustainable Construction,
> U.S. Department of Defense

Buildings that incorporate sustainable features also become models for others to follow and can improve the communities in which they are located. For example, the Herman Miller Corporation's "Green House" regularly provides tours and outreach programs for design and construction professionals as well as for businesses that are planning their own sustainable buildings. Communities may experience better environmental and aesthetic quality of life and less traffic congestion (when sustainable buildings make public transportation and bicycle storage accessible).

Environmental Benefits

Many sustainable design strategies reduce disturbance of the natural environment. Sustainable buildings emit lower levels of air pollutants and CO_2 emissions due to decreased energy use achieved through energy-efficient design, use of renewables, and building commissioning. Waste reduction and reduced strain on landfills can be achieved by storing and collecting recyclables, managing construction waste, using recycled-content materials, eliminating unnecessary finishes, and using standard-sized or modular materials and durable products. Sustainable siting preserves woodlands, streams, and other natural areas. Using rapidly renewable materials (bamboo, cork, wheat straw boards, etc.) and certified wood decreases the use and depletion of long-cycle renewable materials and fosters better forest management and biodiversity.

At the U.S. Environmental Protection Agency campus in Research Triangle Park, the design team justified the choice to spend considerably more to build an aboveground garage instead of ground-level paved parking lot. The team placed a high value on the 15 acres of natural woodlands that would have been destroyed by the paved lot.

The Costs and Benefits of Sustainable Design: A Prototype Building Analysis

During this study, analyses were conducted to evaluate the cost savings associated with various sustainable building features in a "prototype" two-story 20,000-ft^2 building hypothetically located in Baltimore, Maryland.[x] The total construction cost of the base- case building to which the sustainable building was compared was estimated to be about $2.4 million. The cost implications of adding sustainable features to this building were modeled using Energy-10 and DOE-2, supplemented by vendor quotes and other cost estimation techniques. The results are summarized in Table S-1, which also shows which sections of the report discuss each feature.

Although some features such as energy efficiency, commissioning, sustainable landscaping, and stormwater management systems added about $47,000 (2%) to the original first cost of the building, the annual cost savings associated with the sustainable features are significant. Annual energy and water costs were reduced by $5900, and annual maintenance and repair costs for the landscaping and parking lot were reduced by $3600 compared with costs for the base-case building. A reduction in churn costs (by using a raised floor) could lower annual costs by an additional $35,000.[xi] When the societal benefits of reducing air pollution are factored in, the total annual cost reduction could be about $47,000, completely offsetting the first cost increase in the initial year of operation. The first cost increase potentially could be further offset by using sustainable materials such as recycled carpet and concrete with fly ash.

Building a Stronger Business Case for Sustainable Design and Construction

This document presents a sound business case for incorporating the principles of sustainability in the design and construction of Federal facilities. In November 2002, the Federal Energy Management Program hosted a workshop to explore the information that would be needed to make this case even stronger. The participants concluded that collecting data on a wide range of projects using consistent protocols for data collection, reporting, and use would help to more definitively assess the costs of sustainable building projects. They also highlighted the need to develop a better understanding of the health, well-being, and other benefits to building occupants. Because worker productivity is so important, the workshop participants called for a better understanding of how productivity can be measured, especially for "knowledge workers" who do not conduct routine tasks that are easily quantified. The participants concluded that further dialogue is needed on methods to better understand the strategic business advantages of sustainable design.

Table S-1. Summary of First Costs and Annual Cost Savings of Sustainable Features in the Prototype Building Analysis [i]

Feature	First Cost Change	Annual Cost Change	Explanation
Energy-efficiency measures	+$38,000	-$4,300	Results of energy simulation models showed that a 37% reduction in annual energy costs could be achieved by a combination of energy-efficiency measures at a total first-cost increase of about 1.6% of the building cost. The simple payback was estimated to be 8.7 years. See Section 2.2.
Commissioning	+$4,200	-$1,300	Commissioning costs about 2% of the heating, ventilation and air conditioning plus control system cost. It can yield a benefit on the order of 10% of annual energy costs, for a payback period of about 3.2 years. See Section 2.2.
Water-savings measures	-$590	-$330	No-water urinals can have lower first costs than their traditional counterparts because less piping is required, thus lowering first costs for the entire package of water-savings measures. All of the water-savings technologies analyzed have favorable economics, with payback periods ranging from 0.3 to 2.8 years. See Section 2.3.
Sustainable landscaping and stormwater management	+$5,600	-$3,600	Landscaping using natural grasses and wildflowers instead of traditional turf, and a sustainable stormwater management system using porous–surface parking lot paving instead of asphalt, have payback periods of 0.8 and 5.6 years, respectively. See Section 2.4.
Subtotal [ii]	**+$47,000**	**-$9,500**	**5-year payback**
Raised floor system and moveable walls	Negligible [iii]	-$35,000	A raised floor system and moveable wall partitions instead of traditional systems would decrease churn costs significantly with very little additional first costs. See Section 2.5.
Sustainable materials	-$51,000	N.A.	Use of various sustainable materials (concrete with slag content, recycled carpet, low-emitting paint, and certified wood doors) reduced the prototype building's first cost by up to $2.60/ft^2, lowering the building's cost by about 2%.[iv] See Section 2.1.
Social cost reduction of air pollution reduction	[v]	-$2,000	Annual reductions in emissions from improved energy performance were estimated to be 0.016 tons of SO_2, 0.08 tons of NO_x and 10.7 tons of CO_2, which might be valued as high as $1090 for SO_2, $800 for NO_x, and $107 for CO_2. By including the sum of these societal cost reductions in the payback calculation for the energy measures, the simple payback period would decrease from 8.7 to 6.0 years. See Section 2.8.1.
Total	**-$3,800**	**-$47,000**	

[i] Values were rounded to two significant digits.
[ii] The costs for features included in the subtotal are more certain than those for the features in the rows below.
[iii] Lower cost of air distribution systems, electrical receptacles and other equipment usually offsets the higher cost of the raised floor itself.
[iv] Sometimes the costs of sustainable materials are higher than traditional ones, so the cost reduction for sustainable materials shown in this table should be viewed as less certain than the other values.
[v] The cost is included in energy-efficient measures.

Executive Summary Endnotes

[i] Brundtland Commission. 1987. *Our Common Future*. United Nations World Commission on Economic Development.

[ii] Principles are from the "Whole Building Design Guide" developed by a consortium of U.S. government agencies. See http://www.wbdg.org.

[iii] LEED has four ratings – platinum, gold, silver, and certified. The rating for a building is determined by adding the number of points the building achieves through its sustainable features. See http://www.usgbc.org.

[iv] U.S. DOE High Performance Buildings website. See URL http://www.eere.energy.gov/buildings/highperformance/.

[v] Milton DK, PM Glencross, and MD Walters. 2000. "Risk of Sick Leave Associated with Outdoor Air Supply Rate, Humidification, and Occupant Complaints." *Indoor Air 2000* 10:212-221.

[vi] Fisk WJ. 2001. "Estimates of potential nationwide productivity and health benefits from better indoor environments: an update." In *Indoor Air Quality Handbook*. eds. JD Spengler, JM Samet, and JF McCarthy, McGraw-Hill, New York.

[vii] Federspiel C. 2000. "Costs of Responding to Complaints." In *Indoor Air Quality Handbook*. eds. JD Spengler, JM Samet, and JF McCarthy. McGraw-Hill, New York.

[viii] Rocky Mountain Institute website: http://www.rmi.org/sitepages/pid221.php.

[ix] National Research Council. 2001. *Energy Research at DOE: Was It Worth It?* National Academy Press, Washington, D.C., p.29.

[x] Baltimore was chosen because it has both a moderately high heating and cooling load. A moderately small office building was chosen because that size represents the 75th percentile within the current stock of office buildings in the U.S. government and a similarly large percentage of private-sector buildings. The base-case building used standard construction and met the ASHRAE 90.1-1999 standard for energy efficiency (this is also the baseline for LEED energy-efficiency credits).

[xi] This summary uses the conservative (low) end of the cost-savings range that was estimated.

Acknowledgements

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This report is dedicated to the memory of Fredrik (Rik) Wiant, an active member of the Interagency Sustainability Working Group, who demonstrated his dedication to sustainable design principles during his career at the Army Corps of Engineers.

Acronyms and Initialisms

AC	air changes
ACH	air changes per hour
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
BEES	Building for Environmental and Economic Sustainability
BGE	Baltimore Gas and Electric Company
BIDS	Building Investment Decision Support
CFC	chlorofluorocarbon
cfm	cubic feet per minute
CO_2	carbon dioxide
COP	coefficient of performance
CSC	Customer Service Center
DEP	Department of Environmental Protection
DOE	U.S. Department of Energy
DWP	Department of Water and Power (Los Angeles)
ECM	energy conservation measure
EE	energy efficient
EER	energy-efficiency ratio
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act of 1992
ESPC	Energy Services Performance Contract
FEMP	Federal Energy Management Program
gpf	gallons per flush
gpm	gallons per minute
GSA	U.S. General Services Administration
HCFC	hydrofluorocarbon
HVAC	heating, ventilation and air conditioning
IFMA	International Facility Management Association
kWh	kilowatt-hour
L/s	liters/second
LEED™	Leadership in Energy and Environmental Design
NERL	New England Regional Laboratory
NO_x	nitrogen oxides
NOI	net operating income
NPDES	National Pollutant Discharge Elimination System
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
PECI	Portland Energy Conservation Inc.
PNNL	Pacific Northwest National Laboratory
ppm	parts per million
psi	pounds per square inch
PV	photovoltaic
RCSOB	Rachel Carson State Office Building
SAD	Seasonal Affective Disorder
SBS	sick building syndrome
SCROB	South Central Regional Office Building
SO_2	sulfur dioxide
TQM	Total Quality Management

TVA	Tennessee Valley Authority
USPS	U.S. Postal Service
UV	ultraviolet
VOC	volatile organic compound
WBDG	Whole Building Design Guide

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A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. By investing in technology breakthroughs today, our nation can look forward to a more resilient economy and secure future.

Far-reaching technology changes will be essential to America's energy future. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a portfolio of energy technologies that will:

- Conserve energy in the residential, commercial, industrial, government, and transportation sectors
- Increase and diversify energy supply, with a focus on renewable domestic sources
- Upgrade our national energy infrastructure
- Facilitate the emergence of hydrogen technologies as vital new "energy carriers."

THE OPPORTUNITIES

Biomass Program
Using domestic, plant-derived resources to meet our fuel, power, and chemical needs

Building Technologies Program
Homes, schools, and businesses that use less energy, cost less to operate, and ultimately, generate as much power as they use

Distributed Energy & Electric Reliability Program
A more reliable energy infrastructure and reduced need for new power plants

Federal Energy Management Program
Leading by example, saving energy and taxpayer dollars in federal facilities

FreedomCAR & Vehicle Technologies Program
Less dependence on foreign oil, and eventual transition to an emissions-free, petroleum-free vehicle

Geothermal Technologies Program
Tapping the Earth's energy to meet our heat and power needs

Hydrogen, Fuel Cells & Infrastructure Technologies Program
Paving the way toward a hydrogen economy and net-zero carbon energy future

Industrial Technologies Program
Boosting the productivity and competitiveness of U.S. industry through improvements in energy and environmental performance

Solar Energy Technology Program
Utilizing the sun's natural energy to generate electricity and provide water and space heating

Weatherization & Intergovernmental Program
Accelerating the use of today's best energy-efficient and renewable technologies in homes, communities, and businesses

Wind & Hydropower Technologies Program
Harnessing America's abundant natural resources for clean power generation

U.S. Department of Energy
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FEMP

FEDERAL ENERGY MANAGEMENT PROGRAM

FEMP works to reduce the cost and environmental impact of the Federal government by advancing energy efficiency and water conservation, promoting the use of distributed and renewable energy, and improving utility management decisions at Federal sites.

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Management Program

For more information, or to order materials contact the FEMP Help Desk at

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October 2003

U.S. Department of Energy
Energy Efficiency and Renewable Energy

1.0 Introduction

As concern for the environmental and societal impacts of modern development increases, Federal decision-makers are being faced with a challenge: how can the government build, operate, and maintain facilities that minimize impacts on the environment and provide a healthy, productive, and secure work places without increasing costs? This document serves as a resource to parties involved in both Federal government and private-sector construction projects to help them dispel mistaken assumptions and to better defend the decision to incorporate the principles of sustainability in their projects. The "business case" for sustainable design and construction focuses on economic benefits, but as the document reveals, some economic benefits are actually derived indirectly from the very environmental and social benefits that sustainable buildings provide.

This section explains the basic philosophical underpinnings of the sustainable design and construction movement, provides some background on sustainable design in a Federal context, and introduces the "triple bottom line" framework – economic, social and environmental – that is used in this document for examining the benefits of sustainable design and construction.

1.1 What is Sustainable Design and Construction?

The concept of ***sustainable development*** grew from the concern that the world population's consumption of resources and production of wastes could exceed the earth's capacity to produce those resources and absorb those wastes. In 1987, the United Nations World Commission on the Environment (the Brundtland report) defined sustainable development as "those paths of social, economic and political progress that meet the needs of the present without compromising the ability of future generations to meet their own needs."

The concept of sustainability includes three goals or "cornerstones":

- **Environmental stewardship** – protecting air, water, land, and ecosystems, as well as conserving resources, including fossil fuels, thus preserving the earth's resources for future generations
- **Social responsibility** – improving the quality of life and equity for individuals, communities, and society as a whole
- **Economic prosperity** – reducing costs, adding value, and creating economic opportunity for individuals, organizations, communities, and nations.

This "***triple bottom line***" framework, as it is often called, shows the three cornerstones as separate components to make sure all three are emphasized. Advocates believe that only by pursuing all three of these interrelated goals will the earth return to a sustainable path. Organizations that apply this framework in their decision-making recognize that by considering the environmental and social impacts of their actions, as well as traditional short-term financial indicators, they may increase their prospects of sustainable, long-term success.

To achieve tangible results, the principles of sustainable development must be translated into practical guidelines that can be applied in the real world. ***Sustainable design*** involves shifting away from processes and products that pollute, use nonrenewable resources, and have other negative consequences for society and moving toward products and processes with minimal environmental and natural resource impact and that provide ***benefits*** to society. Several frameworks have been developed to help designers of all kinds of products, including buildings and facilities, take steps toward the goals of improving societal well-being and minimizing pollution and natural resource depletion.

One of the important sustainable design frameworks for buildings is called ***Leadership in Energy and Environmental Design*** (LEED™). Developed by the U.S. Green Building Council, LEED is a voluntary, consensus-based rating system that awards different levels of "green" building certification based on total credit points earned.[1] LEED gives credits for incorporating specific sustainable design strategies into a building. The design strategy categories (and their potential points, out of a possible total of 69) include the following:

- Sustainable sites (14)
- Water efficiency (5)
- Energy and atmosphere (17)
- Materials and resources (15)
- Indoor environmental quality (13)
- Innovation and design process (5).

The U.S. Green Building Council plans to update the rating system periodically and add new categories of buildings (the currently approved system is for commercial buildings).[2]

The Federal government has also developed various tools and guidelines for increasing the sustainability of buildings and facilities. A major contribution was the development of the "Whole Building Design Guide (WBDG)," a web-based resource providing information and resources to support sustainable design.[3] This guidance was produced and is updated through an interagency effort. Similar to the LEED principles, the fundamental strategies for sustainable design in the WBDG include the following:

- Optimizing site potential
- Minimizing energy consumption
- Protecting and conserving water
- Using environmentally preferable products and materials
- Enhancing indoor environmental quality
- Optimizing operations and maintenance (O&M) practices.

Another concept that underpins sustainable design is integrating the architectural and mechanical features of the facility to minimize energy and resource use and reduce cost while maintaining comfort. When project developers commit early to a high level of building integration, they can more effectively exploit cost-effective tradeoffs. Integrating sustainable design principles early in the process is also important because that is when the project-defining decisions (and major design mistakes) are made (Lotspeich et al. 2002). Sustainable design considerations should be included in solicitations for architectural and engineering services, the Program of Requirements, and the contracts, as well as in the value engineering process (See Case Study 4-3 in Section 4).

> *"By the time 1% of project costs are spent, roughly 70% of the life-cycle cost of the building has been determined; by the time 7% of costs have been spent, up to 85% of life-cycle costs have been determined."*
>
> Lotspeich et al. (2002)

[1] To become "certified," a building must earn between 26 and 32 points; to obtain a "silver" rating – 33 to 38 points; a "gold" rating – 39 to 51 points; and a "platinum" rating – 52 or more points.
[2] More information about the rating system can be obtained from http://www.usgbc.org.
[3] See http://www.wbdg.org/index.asp.

1.2 Sustainable Design and Construction in the Federal Government Sector

The business case for sustainable design takes on special meaning when discussed in the context of the Federal government, whose mission is to protect the well-being of the nation. As a rule, the government wants to provide an example for others to follow by reducing environmental impacts, lowering energy and resource use, and having positive social impacts on its employees and the communities surrounding its facilities.

Government efforts to implement sustainable design have potentially large impacts. The Federal government owns about 500,000 facilities worldwide, valued at more than $300 billion (National Research Council 1998). It spends over $20 billion annually on acquiring or substantially renovating Federal facilities, and it uses over $3.5 billion annually for energy to power, heat, and cool its buildings (Federal Facilities Council 2001). In addition, the government spends almost $200 billion for personnel compensation and benefits for the civilian employees occupying these buildings (U.S. Office of Personnel Management 2003). Building designs that reduce energy consumption while also providing a healthy and pleasant environment for occupants will result in more cost-efficient government operations and lower environmental impacts that affect the public.

> *"The Federal government has many leaders in this field already, and together we can demonstrate that a sustainable building is healthier, more environmentally sound, operationally and economically viable, and the way we should be doing business."*
>
> John L. Howard, Jr.,
> Federal Environmental Executive

The Federal government's building-related energy costs have dropped over 23% per square foot between 1985 and 2001, saving taxpayers $1.4 billion annually.[4] These savings are the direct result of a number of Federal laws and Executive Orders. The Energy Policy Act (EPAct) of 1992 was the latest in a series of laws since 1975 that have recognized the Federal government's own role as a very large consumer of energy and other products. EPAct provided guidance on how to improve energy performance and set goals for Federal energy and water use and required all government buildings to install energy and water conservation measures that have a payback period of less than 10 years.

The Federal commitment to green buildings was further advanced by the promulgation of several key Executive Orders later in the 1990s. In June 1999, the White House promulgated Executive Order 13123, requiring agencies to apply sustainable design principles to the design and construction of new facilities and setting goals for reducing energy use beyond EPAct levels, lowering greenhouse gas emissions and water consumption, and increasing renewable energy and green power purchasing. It also mandated that agencies build showcase facilities with advanced energy-efficiency technologies.

Executive Order 13123 and EPAct emphasize the need for lifecycle[5] cost-effective solutions. In other words, government agencies were asked to compare options based on costs over the lifetime of the facility and its equipment, not just on initial capital outlays. Lifecycle-cost analysis often supports adding sustainable design features because the annual cost savings associated with these features over their lifetimes often offset higher first costs. On the other hand, the cost-effectiveness requirement can be an impediment to some sustainable design features that are more expensive on a lifecycle basis than their traditional counterparts.

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[4] Personal communication with C. Tremper, McNeil Technologies, Springfield, Virginia.

[5] Lifecycle cost represents the first cost plus the replacement costs (discounted to present value)that occur over the lifetime of the equipment, minus the discounted present value of the stream of cost savings.

Despite the lifecycle costing requirements, government project managers still find it hard to include all the sustainable design features they would like to see in building projects. Because O&M costs are appropriated and managed separately from capital expenditures, agencies find it difficult within their normal budgeting process to use lifecycle cost analysis, which intertwines capital and O&M into one comprehensive metric. Capital budgets are usually preset for construction projects, so increasing the budget to include the extra cost of sustainable design features is difficult. Interpretations of how lifecycle costs should be considered in government construction projects vary between agencies and even within agencies.

Nevertheless, as this report documents, Federal agencies have found creative ways to stay within capital budgets while making their buildings "green," and many Federal agencies have developed policies and programs to support sustainable design. Although policies vary from agency to agency, most encourage the use of LEED or some similar system. For example, the Army worked with the U.S. Green Building Council to develop the Sustainable Project Rating Tool (SPiRit), an adaptation of LEED that meets the specific needs of the Army.

1.3 A Framework for Understanding the Benefits of Sustainable Design and Construction

Questions raised about sustainable design often include the following: What does it cost? What are the benefits? To help answer these questions, this document uses the "triple bottom line" benefits framework described in Section 1.1 and applies it to sustainable building design and construction, as depicted in Figure 1-1. The three categories of benefits – economic, social, and environmental – were fully explored, and each type of benefit was documented with hard "evidence," to the extent possible.

Economic benefits to the building owner include first-cost and operating-cost savings. In addition, as Figure 1-1 indicates, environmental and social benefits can lead to economic benefits for building owners. For example, sustainable design efforts to improve the quality of the indoor environment can result in lower absenteeism and higher productivity of building occupants and hence lower personnel costs; and the building's better environmental profile can reduce the time for and cost of permitting the facility. In addition to the building owner, other stakeholders such as neighbors, local and state governments, and society as a whole may reap economic benefits, including lower damage costs from pollution, reduced municipal infrastructure costs, and local/regional economic growth due to the emerging businesses related to sustainable design and construction.

A principal ***social*** benefit of sustainable design is the improved health, satisfaction, and well-being of building occupants. Sustainable design features can also go hand in hand with improved building safety and security. Federal facilities designed using the principles of sustainability can also have positive social impacts on the surrounding community, such as the transfer of pollution prevention and recycling practices to the private sector, increased use of public or alternative transportation, and improved brownfield sites.[6]

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[6] Brownfields are abandoned, idled, or underused industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination (http://www.epa.gov/ebtpages/cleabrownfields.html).

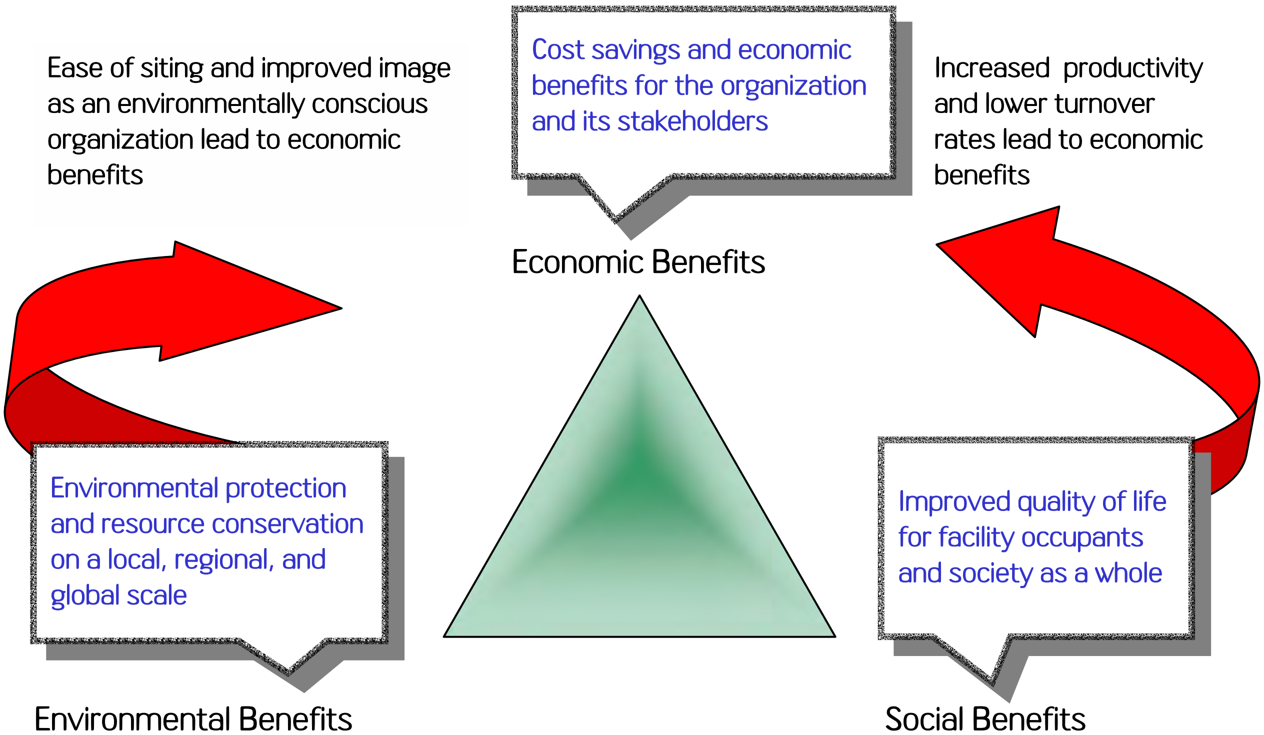

Figure 1-1. "Triple Bottom Line" Benefits of Sustainable Design

Environmental benefits have been a main driver behind the sustainable design movement. Sustainable facilities typically use lower amounts of fossil fuels, create less air pollution and greenhouse gas emissions, result in less waste for disposal in landfills, consume less water and other natural resources, use fewer virgin building materials, disturb less land, and are more sensitive to existing ecosystems.

Three principal forms of "evidence" of the benefits of sustainable design form the basis for the documentation presented in this document:

- First, under Federal Energy Management Program's (FEMP's) direction, the Pacific Northwest National Laboratory (PNNL) and the National Renewable Energy Laboratory (NREL) conducted engineering cost analyses to estimate the potential cost savings associated with various sustainable features in buildings. One challenge encountered when developing the business case is that there is no comprehensive source of data on the costs of sustainable design features. To address this challenge, this study developed "typical" costs based on available data from various sources, including vendors of sustainable building products. Cost savings were estimated for a "prototype" two-story 20,000-ft^2 office building hypothetically located in Baltimore, Maryland.[7] The analysis estimated lifecycle cost savings associated with improving energy-efficiency, commissioning the building, reducing water consumption, using sustainable landscaping approaches, using underfloor systems to reduce churn costs, and choosing sustainable building materials.

[7] Baltimore was chosen because it has both a moderately high heating and cooling load. A moderately small office building was chosen because that size represents the 75th percentile within the current stock of office buildings in the U.S. government and a similarly large percentage of private-sector buildings.

In Sections 2, 3 and 4 of this document, the portions of the text that discuss this prototype building analysis are identified with the "green building" icon (left).

- Second, the document contains numerous real-world case studies that illustrate the benefits of sustainable design. These case studies document benefits achieved in both government and private-sector building projects.

- Third, the document includes summaries of research studies that rigorously examined benefits such as improved occupant productivity, health, and well-being associated with various sustainable design features.

The results of this data-gathering exercise show that a strong business case for sustainable design exists. Table 1-1 summarizes the economic, social, and environmental benefits of the six principal elements of sustainable design, which correspond closely to the categories in the LEED rating system and the WBDG.

The next three sections of this document expand on each of the columns in the figure and provide the available evidence for the economic (Section 2), social (Section 3), and environmental (Section 4) benefits shown in Table 1-1. The table indicates which subsection discusses each type of benefit. The final section of the main body of the document (Section 5) describes the kind of data and information that could be gathered to make the business case for sustainable design and construction even stronger than it is today. Section 6 lists the references cited in this study.

Several appendixes provide additional detail and data and are included at the end of the document. Appendix A expands Table 1-1 into a much more detailed list of sustainable design features and their economic, social, and environmental benefits. Appendix B provides details on the energy analysis conducted for the prototype building analysis. Appendix C describes the results of an exercise, similar to the prototype building analysis, which examined the costs and benefits of the range of sustainable design features in a building at the Tennessee Valley Authority. Appendixes D and E summarize the analysis of sustainable siting and water-saving features, and the sustainable materials analysis, respectively. Appendix F contains a detailed discussion of the body of research conducted on occupant productivity, health and comfort, and satisfaction.

Table 1-1. Benefits of Sustainable Design and Construction

Element	Economic Benefits	Social Benefits	Environmental Benefits
Sustainable siting	Reduced costs for site preparation and clear-cutting, and parking lots and roads. *See Section 2.1.* Lower energy system cost due to optimal orientation. *See Section 2.1.* Less landscape maintenance costs. *See Section 2.4.*	Improved aesthetics (e.g., better appearance of site to neighbors). Increased transportation options for employees. *See Section 3.4.*	Land preservation. Lower resource use. Protection of ecological resources. Soil and water conservation. Reduced energy use and air pollution. *See Sections 4.1 and 4.3.*
Water efficiency	Lower first cost (for some fixtures). *See Section 2.1.* Reduced annual water costs. *See Section 2.3.* Lower municipal costs for wastewater treatment. *See Section 2.8.*	Preservation of water resources for future generations and for recreational and agricultural uses. Fewer wastewater treatment plants and associated annoyances. *See Section 3.4.*	Lower potable water use and pollution discharges to waterways. Less strain on aquatic ecosystems in water-scarce areas. Preservation of water resources for wildlife and agriculture. *See Section 4.3.*
Energy efficiency	Lower first costs when systems can be downsized as the result of integrated energy solutions. *See Section 2.1.* Up to 70% lower annual fuel and electricity costs; reduced peak power demand. *See Section 2.2.* Reduced demand for new energy infrastructure, lowering energy costs to consumers. *See Section 2.8.*	Improved thermal conditions and occupant comfort satisfaction. *See Section 3.2.* Fewer new power plants and transmission lines and associated annoyances. *See Section 3.4.* Improved safety and security. *See Section 3.3.*	Lower electricity and fossil fuel use, and the accompanying reduced air pollution and carbon dioxide emissions. *See Section 4.1.* Decreased impacts of fossil fuel production and distribution. *See Section 4.3.*
Materials and resources	Decreased first costs due to material reuse and use of recycled materials. *See Section 2.1.* Lower costs for waste disposal and decreased replacement cost for more durable materials. *See Section 2.4.* Lower municipal costs for new landfills. *See Section 2.8.*	Fewer landfills and associated nuisances. Expanded market for environmentally preferable products. Decreased traffic due to use of local/regional materials. *See Section 3.4.*	Reduced strain on landfills. Reduced use of virgin resources. Healthier forests due to better management. Lower energy use for material transportation. Increased local recycling market. *See Sections 4.2 and 4.3.*
Indoor environmental quality	Organizational productivity improvements from improved worker performance, lower absenteeism, and reduced staff turnover. *See Section 2.6.* Lower disability/health insurance costs and reduced threat of litigation. *See Section 2.7.*	Reduced adverse health impacts. Improved occupant satisfaction and comfort. Better individual productivity. *See Sections 3.1 and 3.2.*	Better air quality inside the facility, including reduced volatile organic emissions, carbon dioxide, and carbon monoxide. *Discussed in the context of health impacts in Section 3.1.*
Commissioning and O&M	Reduced energy costs. *See Section 2.2.* Reduced costs of dealing with complaints. *See Section 2.7.* Longer building and equipment lifetimes. *See Section 2.7.*	Increased occupant productivity, satisfaction, and health. *See Sections 3.1 and 3.2.*	Lower energy consumption, as well as air pollution and carbon dioxide emissions and other environmental impacts of energy production and use. *See Section 4.1.*

2.0 The Economic Benefits of Sustainable Design

Evidence is growing that sustainable buildings provide financial rewards for building owners, operators, and occupants. Sustainable buildings typically have lower annual costs for energy, water, maintenance/repair, churn (reconfiguring space because of changing needs), and other operating expenses. These reduced costs do not have to come at the expense of higher first costs. Through integrated design and innovative use of sustainable materials and equipment, the first cost of a sustainable building can be the same as, or lower than, that of a traditional building. Some sustainable design features have higher first costs, but the payback period for the incremental investment often is short and the lifecycle cost typically lower than the cost of more traditional buildings.

In addition to direct cost savings, sustainable buildings can provide indirect economic benefits to both the building owner and society. For instance, sustainable building features can promote better health, comfort, well-being, and productivity of building occupants, which can reduce levels of absenteeism and increase productivity. Sustainable building features can offer owners economic benefits from lower risks, longer building lifetimes, improved ability to attract new employees, reduced expenses for dealing with complaints, less time and lower costs for project permitting resulting from community acceptance and support for sustainable projects, and increased asset value. Sustainable buildings also offer society as a whole economic benefits such as reduced costs from air pollution damage and lower infrastructure costs, e.g., for avoided landfills, wastewater treatment plants, power plants, and transmission/distribution lines.

Section 2.1 explains how using integrated design and various low-cost sustainable features reduces first costs. Sections 2.2 through 2.5 discuss the other direct economic benefits: annual operating cost savings for energy, water, maintenance and repair, and churn. Sections 2.6 and 2.7 discuss the indirect benefits of sustainable buildings for building owners, and Section 2.8 discusses the indirect benefits of sustainable buildings for society. Case studies and research summaries illustrating various benefits are included in each section.

2.1 Lower (or Equal) First Costs

Sustainable design must begin at the conceptual stage of a project to realize the full benefits. The first step is to form a design team – including the owners; architects; engineers; sustainable design consultants; landscape designers; O&M staff; health, safety and security experts; the general contractor and key subcontractors; cost consultants and value engineers; and occupant representatives. This team needs to work together from the start, seeking an "integrated" design. The team develops innovative solutions that meet energy, environmental, and social goals while keeping costs within budget.

> *"As the green design field matures, it becomes ever more clear that integration is the key to achieving energy and environmental goals especially if cost is a major driver."*
>
> Building Green Inc. (1999)

Using their collective, interdisciplinary analytical capability, the team can incorporate many strategies that, taken alone, would increase first costs. For example, by improving the building envelope, the design team can often eliminate the heating, ventilation, and air conditioning (HVAC) system around the perimeter of the building (and the associated ducting) and also downsize the primary HVAC system. Downsizing the HVAC system and eliminating ducting release money to pay for the envelope improvements. A good example of this phenomenon occurred during the design of the Pennsylvania Department of Environmental Protection's Cambria Office Building. When designers of this building first proposed an upgrade to triple-glazed, double low-e windows, the developer balked at the $15,000 increase in cost. However, the developer was won over when it was demonstrated that this upgrade would allow the perimeter-heating zone to be eliminated for a savings of $15,000, the heat pumps to be downsized for an additional $10,000 savings, and additional space to be gained because of the smaller equipment and ducts for additional rent of $5,000.[8] Also, by eliminating unnecessary features (e.g., expensive finishes), the team can add some more expensive sustainable features that not only meet environmental goals but that also reduce operating costs.

In a sustainable design project, the design team conducts a tradeoff exercise – trading off the cost of optional features against the cost of features that will result in energy, environmental, or social improvements. Focusing on integrated solutions and explicitly evaluating tradeoffs can result in a sustainable facility built for the same (or an even lower) cost than a more traditional building. In most of the government case studies of sustainable buildings included in this document, the first costs were not higher than the original budgeted amount. The following are some design and construction strategies that a team can use to reduce first costs:[9]

- **Optimize site and orientation.** One obvious strategy to reduce first costs is to apply appropriate siting and building orientation techniques to capture solar radiation for lighting and heating in winter and shade the building using vegetation or other site features to reduce the summer cooling load. Fully exploiting natural heating and cooling techniques can lead to smaller HVAC systems and lower first costs.
- **Re-use/renovate older buildings and use recycled materials.** Re-using buildings, as well as using recycled materials and furnishings, saves virgin materials and reduces the energy required to produce new materials. Re-using buildings may also reduce time (and therefore money) associated with site planning and permitting.
- **Reduce project size.** A design that is space-efficient yet adequate to meet the building objectives and requirements generally reduces the total costs, although the cost per unit area may be higher. Fully using indoor floor space and even moving certain required spaces to the exterior of the building can reduce first costs considerably.
- **Eliminate unnecessary finishes and features.** One example of eliminating unnecessary items is choosing to eliminate ornamental wall paneling, doors (when privacy isn't critical), and dropped ceilings. In some cases, removing unnecessary items can create new opportunities for designers. For example, eliminating dropped ceilings might allow deeper daylight penetration and reduce floor-to-floor height (which can reduce overall building dimensions).
- **Avoid structural overdesign and construction waste.** Optimal value engineering and advanced framing techniques reduce material use without adversely affecting structural performance.[10] Designing to minimize construction debris (e.g., using standard-sized or modular materials to avoid cutting pieces and generating less construction waste) also minimizes labor costs for cutting materials and disposing of waste.

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[8] "Pennsylvania Department of Environmental Protection's Cambria Office (DEP Cambria)," a case study in DOE's High Performance Buildings Database at http://www.eere.energy.gov/buildings/highperformance/case_studies/overview.cfm?ProjectID=47.

[9] Many of these concepts were outlined in "Building Green on a Budget." Article found at http://www.betterbricks.com, which cites *Environmental Building News* (May 1999), a newsletter published by Building Green at http://www.buildinggreen.com.

[10] These techniques are explained at http://www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=70&DocumentID=2021.

- **Fully explore integrated design, including energy system optimization.** As discussed above, integrated design often allows HVAC equipment to be downsized. Models such as DOE-2 allow energy performance of a prospective building to be studied and sizing of mechanical systems to be optimized. Using daylighting and operable windows for natural ventilation can reduce the need for artificial lighting fixtures and mechanical cooling, lowering first costs. Beyond energy-related systems, integrated design can also reduce construction costs and shorten the schedule. For example, by involving the general contractor in early planning sessions, the design team may identify multiple ways to streamline the construction process.

> *"Discovering the DOE-2 model was invaluable. I can't imagine doing this kind of project without it ever again . . . With this technique, we can actually prove to our clients how much money they will be saving."*
>
> Robert Fox, Principal, Fox & Fowle, Architect of Four Times Square, http://www.betterbricks.com

- **Use construction waste management approaches.** In some locations, waste disposal costs are very high because of declining availability of landfill capacity. For instance, in New York City, waste disposal costs about $75.00 per ton.[11] In such situations, using a firm to recycle construction waste can decrease construction costs because waste is recycled at no cost to the general contractor, thereby saving disposal costs.[12] (For an example, see case Study 4-2 in Section 4.)
- **Decrease site infrastructure.** Costs can be reduced if less ground needs to be disturbed and less infrastructure needs to be built. Site infrastructure can be decreased by carefully planning the site, using natural drainage rather than storm sewers, minimizing impervious concrete side-walks, reducing the size of roads and parking lots (e.g., by locating near public transporta-tion), using natural landscaping instead of traditional lawns, and reducing other manmade infrastructure on the site, when possible. For example, land development and infrastructure costs for the environmentally sensitive develop-ment on Dewees Island, off the coast of Charleston, South Carolina, were 60% below average because impervious roadway surfaces and conventional landscaping were not used.

> *"When you don't have all these manicured landscapes and paved roads, you end up with enormous reductions in infrastructure investment."*
>
> John Knott, Chief Executive of Island Preservation Partnership, Dewee Island's developer
> Source: Rocky Mountain Institute website
> http://www.rmi.org/sitepages/pid221.php

In addition to these strategies, certain materials and fixtures that reduce environmental impact have lower first costs than their traditional counterparts (the costs for these products are described in more detail in Appendixes D and E):

- **Concrete with slag content or fly ash.** This product is made with a mix of Portland cement and either iron mill slag (a waste product from blast furnaces that produce iron)[13] or fly ash (a waste product from coal-fired power plants). Vendor quotes gathered during this study indicate that this type of concrete can be slightly less expensive ($0.50 to $1.00 per ton less) than concrete made with 100% Portland cement and is purportedly more durable.

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[11] High Performance Building Guidelines: http://www.ci.nyc.ny.us/html/ddc/html/highperf.html.
[12] See http://www.epa.gov/epaoswer/non-hw/debris/reduce.htm.
[13] The slag is recycled into ground-granulated blast furnace slag cement by grinding the iron blast furnace slag to cement fineness.

- **Carpet with recycled content.** A range of environmentally preferable carpet products is currently available on the market, including refurbished used carpet and new carpet made from various combinations of old carpet, carpet scraps, carpet backing, auto parts, soda bottles, and flooring materials. The quotes gathered for this study indicate that such sustainable carpet options can cost as much as $15 less per yard than traditional carpet (although some price quotes indicated the recycled carpet was more expensive).

- **Low-emitting paint and recycled paint.** Low-emitting paint has very low or no emissions of volatile organic compounds (VOCs) when it is applied. For building occupants, the paint significantly reduces negative reactions that normal latex paint often causes and allows buildings to be occupied during or shortly after the paint is applied. Price quotes gathered for this study vary, but some indicate that low-emitting paint can cost $3 per gallon less than normal paint and can cover more surface area per gallon.[14]

  Recycled paint is "left-over" paint collected from construction sites or the paint manufacturing process. That paint is then sorted by type, color, and finish and reprocessed for resale. Price quotes collected for this study indicate that recycled paint can sometimes be $15 per gallon less expensive than comparable "virgin" contractor-grade latex paint.

- **Certified wood products.** Such products comply with Forest Stewardship Council Guidelines, indicating that wood producers have applied all regional laws and international treaties, respect long-term tenure, and use rights on the land from which the wood is harvested. Price quotes indicate that some certified wood doors are $150 less expensive than traditional doors (although some are more expensive).

- **No-water urinals.** Urinals that use no flushing water often cost less to install than traditional, water-using urinals because of the reduced need for pipes (no intake water is required). Price quotes indicate that some brands of no-water urinals cost over $280 less (per urinal, installed) than their water-using counterparts. (Also, see Section 2.3 for annual water cost savings).

Implementing all of the sustainable features discussed above (concrete with slag content, recycled carpet, low-emitting paint, certified wood doors, and no-water urinals) reduced the first costs of the prototype building that was examined in this study (see Section 1) by up to $2.60/ft^2 and the total first cost of the building construction by as much as $51,000, lowering the total building cost by about 2%.

Case Study 2-1 shows how reducing project size and using integrated design principles can significantly reduce first costs. Focusing only on strategies that keep first costs low may not be in the best long-term interest of the building owner. Some features that increase first costs can significantly reduce lifecycle costs. Some of these lifecycle cost reduction strategies are discussed in Sections 2.2 through 2.5.

[14] Various brands of low-emitting paint were compared with their traditional counterparts. To provide reasonable points of comparison with the low-emitting paint, costs for both normal contractor-grade and high-end products were included. The cost of the low-emitting paint varied depending on location of the purchase, volume of the paint purchased, and the ability of the local distributor to offer special rates.

Case Study 2-1: Zion National Park Visitors Center Reduces Energy Consumption While Cutting Construction Costs

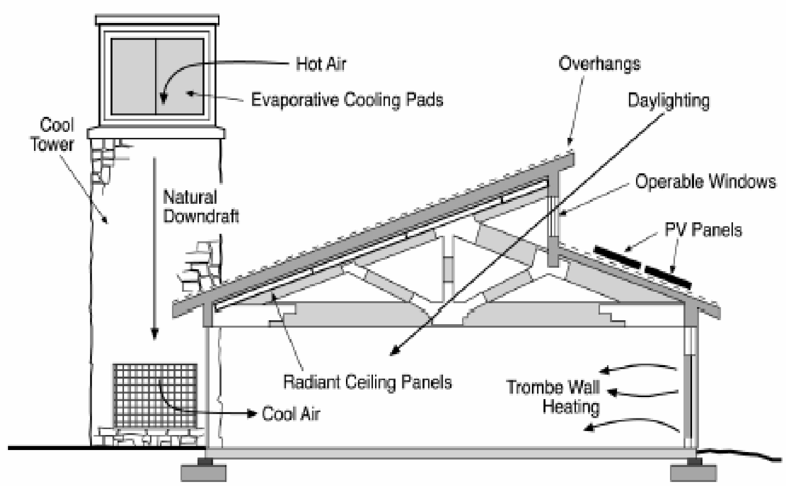
This case study shows that an integrated design team can apply fairly simple natural principles in innovative ways to significantly reduce energy consumption. A high-performance building does not necessarily cost more to build than a more typical building. One way to reduce first costs is to consider making changes to the general building program (overall concept, scope, and requirements). In this case study, exhibit space was moved outdoors.

Project Description: The Zion National Park Visitors Center in Springdale, Utah, is a small building (7,600 ft^2) designed to allow park visitors access to park information, interpretation, and trip-planning assistance. The facility provides both indoor and outdoor exhibit spaces.

Approach to Sustainable Design: The design team used a "whole building design" process from the onset of the conceptual design through completion of the commissioning process. Instead of using a two-staged design approach in which the building design is developed first, followed by the engineering design of the heating, lighting, and other mechanical systems, this design team viewed the building project as a single system. The team worked to ensure that the building envelope and systems complemented each other. Extensive whole-building energy and lighting computer simulations were conducted throughout the design process.

Sustainable Features: The building includes features such as natural ventilation and evaporative cooling, passive solar heating, daylighting and sunshading, computerized building controls, and an uninterruptible power supply integrated with a photovoltaic system. The natural ventilation and cooling are facilitated by a cooltower, a passive solar approach that has been used for hundreds of years. Water is pumped onto a honeycomb media at the top of the tower, cooling the air by evaporation. This cool air descends naturally (without fans) through the tower and into the building. Strategically placed windows help evacuate hot air and circulate the air. The building's envelope and general form, including overhangs, clerestories, roofline, and massive building materials, help reduce energy consumption.

After the building envelope was designed, the small amount of remaining heating required was met with electrically powered radiant heating panels, which were estimated to be the most cost-effective solution and eliminated the need for a central heating system that would have required a hot-air furnace or boiler and associated ductwork or piping. Daylighting (provided by clerestory windows and windows six feet above the floor) meets the primary lighting needs, but a high-efficiency electric lighting system and related controls were designed to complement the daylighting design. The uninterruptible power supply system was included in the original

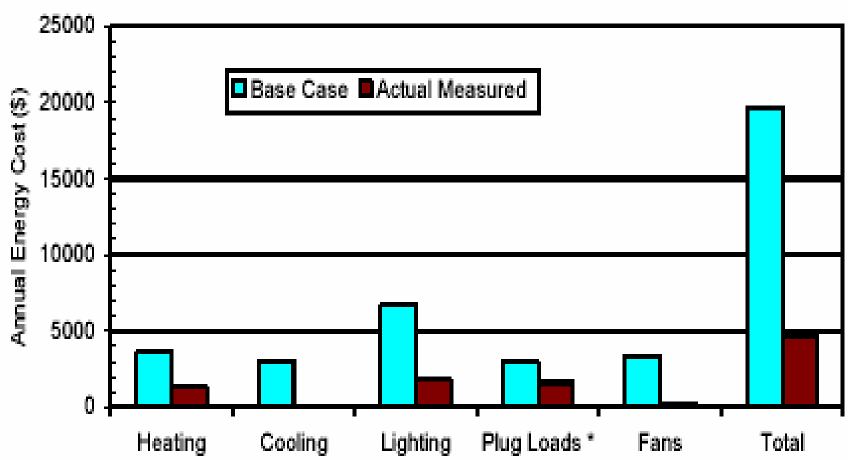


Energy-Related Features of the Visitors Center

plan for the building's electrical system because of poor power reliability at the site. The design team specified an inverter that could handle input from a solar-electric system, so the building was ready to be outfitted with a solar-electric system. Later in the design process when additional funding was available, a 7.2-kW solar-electric system was installed. The figure (previous page) shows the design's main features.

Financial Considerations: The project construction cost was estimated to be about 30% less than that of a conventional visitors center. This lower cost is primarily the result of a decision made early in the design process to move many of the exhibit spaces outdoors under permanent shade structures to decrease building size. To ensure that the outdoor exhibits were noticed, the designers separated the visitors center from the restrooms (comfort station), so visitors would walk through the outdoor exhibit space.

In addition, the floor space required for the building support functions (i.e., the mechanical room) was smaller than in a conventional visitors center because eliminating ducts, large blowers, chillers, and boilers reduced the size of the mechanical room. Eliminating the need for fuel storage (by using electrically powered radiant heat) also reduced infrastructure costs. The figure below summarizes annual energy costs based on measured performance (NREL monitored the performance). The building was designed to use most of its power during offpeak periods, when power is cheaper. The building's operating costs is only $0.45/ft^2 ($4.84/m^2) to operate. The NREL team found that the Zion Visitors Center Complex is using 70% less energy compared with facilities built to the applicable Federal codes.[15] This energy use is equivalent to a total annual savings of about 250,000 kilowatt-hours (kWh) (870 million Btu).



Measured Energy Cost Performance of the Visitors Center (Torcellini et al. 2002)

Sources: Torcellini et al. (2002); DOE's High Performance Buildings Database at URL: http://www.eren.doe.gov/buildings/highperformance/case_studies/overview; and personal communication with P. Torcellini, NREL, Golden, Colorado.

[15] The 70% reduction was calculated from a theoretical base-case building, which was modeled to provide a starting point for the analysis and as a metric for evaluating the project's energy-savings success. The base-case model has the same footprint area as the as-built building. The base-case building is solar neutral (equal glazing areas on all orientations) and meets the minimum requirements of the Federal Energy Code (10 CFR 34). Electric lights provided all lighting for the base-case building and were set to retail and exhibit lighting levels. More detail on the base-case versus as-built building is available from Torcellini et al. (2002) on DOE's Energy High Performance Buildings website: http://www.eren.doe.gov/buildings/highperformance/case_studies/overview.

2.2 Annual Energy Cost Savings

A wide range of building design approaches and commercially available technologies can help effectively minimize a building's energy costs. As Section 2.1 discussed, an important concept in energy-efficient design is integrating the building's architectural and mechanical features to minimize energy use and reduce cost while maintaining comfort. This integration is best done during the very early stages, when the most cost-effective holistic system can be designed. Although some energy-efficiency strategies result in slightly higher first costs, the resulting annual cost savings result in lower lifecycle costs.

To illustrate this concept, PNNL and NREL analyzed the energy costs that could be saved by using an integrated design approach to alter architectural elements and mechanical systems in the prototype two-story building of 20,000 ft^2, hypothetically located in Baltimore, Maryland. The base-case building, to which the sustainable building was compared, is assumed to meet the levels of energy efficiency in the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) 90.1-1999 standard (this is also the baseline for LEED energy-efficiency credits). The total construction cost of this base-case building was estimated at $2.4 million. Using two energy simulation models (Energy-10 and DOE-2.1e) and standard costing approaches (see Appendix B for details), the analysis team calculated the incremental first cost[16] and annual energy cost savings, as well as lifecycle costs[17] and payback periods, for a combination of energy-saving features, optimized for lowest energy use and lifecycle cost (see Figure 2-1).

The results indicate that annual energy costs could be reduced 37% below the base case[18] by incorporating various energy-saving features, at a total first cost increase of about $38,000 (adding 1.6% to total first costs). The overall simple payback[19] for the changes was estimated to be 8.7 years, and the sustainable building had a net lifecycle savings of over $23,000 during the assumed 25-year lifetime. The savings-to-investment ratio[20] was estimated to be 1.5. Table 2-1 shows the breakout of the savings. For example, the added skylights, combined with lower overall lighting intensity and lighting controls, decreased the lighting energy consumption by about 48% and saved over $2900 in annual energy costs. Table 2-2 compares some additional values between the base case and the sustainable option (prototype building).

The energy-efficiency analysis of the prototype building indicates that significant amounts of energy can be reduced within an acceptable payback period and that energy-efficient buildings can have lower lifecycle costs than their traditional counterparts. The cost analysis of the Johnson City Customer Service Center being designed by the Tennessee Valley Authority (Appendix C) provides another example.

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[16] Incremental first cost is the additional capital expenditure needed to include the sustainable design feature (a negative incremental first cost indicates a capital cost savings).

[17] Lifecycle cost represents the first cost plus the replacement costs (discounted to present value) that occur over the lifetime of the equipment, minus the discounted present value of the stream of cost savings.

[18] This value excludes "plugloads," the energy use by equipment and machines in buildings.

[19] Simple payback equals the incremental first cost divided by the annual cost savings.

[20] The savings-to-investment ratio is similar to a benefit-cost ratio and equals the discounted present value of the stream of annual cost savings over the lifetime of the investment, divided by the incremental first cost plus the discounted value of future replacement costs. A savings-to-investment ratio greater than 1.0 indicates that the present value of the savings exceed the present value of any additional capital outlays.

Energy-Efficiency Measures Examined in the Prototype Building Analysis

Lighting Measures

- **Increased daylighting.** Skylights were added, increasing daylight to the top floor.
- **Reduced lighting intensity.** Lighting power densities recommended by the Illuminating Engineering Society of North America and ASHRAE, as a proposed addenda to the 90.1 standard, were adopted. The lighting level was reduced from 40 to 35 footcandles in the office area, with some increase in task lighting.
- **Perimeter daylighting controls with dimmers.** Daylight sensors (six per floor) control stepped ballast controls so that electric lighting is dimmed when sufficient daylight exists. In the base case, no dimming of electric lighting occurs.

Envelope Measures

- **Window distribution.** The square footage of the windows was redistributed to optimize solar gain with heating and cooling costs. The optimized window-to-wall ratio is 15% window for the north wall, 10% window for the east and west walls, and 30% window for the south wall. The base-case ratio is 20% for all walls.
- **Additional wall insulation.** On the outside face of the exterior wall framing, R-10 rigid insulation was added compared with only R-13 batt insulation in the base-case walls. The resulting insulation in the sustainable building was R-23.
- **Additional roof insulation.** The R-15 rigid insulation was increased to R-20.
- **White roof.** A white roof finish material with low solar radiation absorptance of 0.30 was used compared with the base case's absorptance of 0.70.
- **Highly energy-efficient windows.** The sustainable option balances window performance with the low lighting levels and the use of daylighting controls. The result is a cost-optimized window with a U-factor of 0.31 and a shading coefficient of 0.39.

Mechanical Systems

- **High-efficiency air conditioner.** The air conditioning unit has an energy-efficiency ratio of 13 compared with 10 for the base case.
- **High-efficiency water heater.** A 90% thermal efficiency condensing water heater was used compared with a commercial gas water heater with 80% thermal efficiency for the base case.
- **Low-pressure ducts.** The fan external static pressure was reduced from 1.0 inch water column to 0.5 inch water column by enlarging the duct sizes.
- **Economizers.** An integrated economizer, including an outside air enthalpy sensor with a high-limit enthalpy setpoint, was used; the setpoint was set at 25 Btu/lb in conjunction with a dry bulb temperature high limit of 74°F.

Figure 2-1. Energy-Efficiency Measures Examined in the Prototype Building Analysis

Table 2-1. Prototype Building Analysis: Energy-Efficiency Features Reduce Annual Energy Costs by 37%

	Base-Case Building Annual Energy Cost	Sustainable Building Annual Energy Cost	Percent Reduction
Lighting	$6,100	$3,190	47.7
Cooling	$1,800	$1,310	27.1
Heating	$1,800	$1,280	28.9
Other	$2,130	$1,700	20.1
Total	$11,800	$7,490	36.7
* Values are rounded to three significant digits.			

Table 2-2. Prototype Building Analysis: Costs and Benefits of Energy-Efficiency Measures*

		Sustainable Building
Total first cost of building (thousand $)	$2,400	$2,440
Annual energy cost		
Dollar amount	$11,800	$7,490
Percent change from base case	NA**	-36.7
Economic metrics		
Simple payback period (yr)	NA	8.65
Lifecycle cost (thousand $)	$2,590	$2,570
Percent change in lifecycle cost from base case	NA	-0.85
Savings-to-investment ratio	NA	1.47
Energy use		
Million Btu	730	477
Percent change from base case	NA	-34.6
* Values have been rounded to three significant figures. ** NA = not applicable.		

In addition to integrating architectural elements and high-efficiency mechanical systems to reduce annual energy use, various measures can be taken to lower the energy use by equipment and machines in buildings (plug loads). For instance, the marketplace now offers Energy Star™ computers, office machines, and appliances,[21] and the Federal government mandates the purchase of these energy-efficient machines for its facilities. In addition, innovative entrepreneurs have begun introducing new products that help reduce unnecessary energy consumption and have short paybacks. For example, one commercially available device reduces the electricity consumed by vending machines by up to 46% with a payback period of 1 to 2 years, while maintaining the proper temperature of the beverages or other products.[22]

Another important aspect of achieving energy efficiency in a new building is "commissioning," which refers to the validation and checking process undertaken before the building is occupied to ensure that the performance of the building and its systems satisfies both the design intent and occupants' needs. In sustainable building design and construction, the need to commission is greater than ever because of the interactive synergies between the various mechanical and electrical systems and the building's architectural features (U.S. General Services Administration [GSA] and U.S. Department of Energy [DOE] 1998). Data substantiating the benefits of commissioning new buildings are difficult to obtain because benefits must be estimated against a modeled baseline or compared with a similar building. However, a database of 175 commissioning case studies by Portland Energy Conservation, Inc. (PECI) (1997) of various types of commercial buildings ranging from new to 74 years old consistently demonstrated significant energy savings and improvements in thermal comfort, indoor air quality, and overall O&M. Table 2-3 shows the estimated costs of commissioning a new building.

[21] This study did not include a thorough analysis of reducing plug loads. The LEED system does not apply points to this category. In some cases, energy-efficiency improvements depend on the behavior of building occupants and therefore cannot be guaranteed. The plug load in the prototype building represents about 25% of the energy consumption.

[22] www.bayviewtech.com.

Table 2-3. Costs of Commissioning for New Construction (PECI 1997)

	Cost
Whole building	0.5-1.5% of total construction cost
HVAC and automated controls systems only	1.5-2.5% of mechanical system cost
Electrical systems commissioning	1.0-1.5% of electrical system cost

The first cost for the HVAC and control system in the prototype building analyzed in this study was about $212,000 (out of a total cost of $2.4 million), and the annual energy costs of the base case were modeled to be $11,800. Using the values in Table 2-3, commissioning the HVAC and control system would cost from $3180 to $5300 (1.5% to 2.5% of HVAC and control system costs). Assuming that the commissioning would reduce energy costs by 10%,[23] the annual costs savings would be about $1310, resulting in payback period from 2.4 to 4.0 years.

In addition to commissioning the building before it is occupied, a building designed for sustainability must also be operated and maintained with the same goal in mind. O&M activities include 1) controlling and optimizing procedures and systems and 2) performing routine, preventive, scheduled, and unscheduled actions to prevent equipment failure or decline and to meet efficiency, reliability, and safety goals.

In a sustainable design environment, O&M requirements must be identified and addressed in a building's planning stage to ensure that control systems are installed, that the building and equipment are designed for ease of O&M, and that sufficient O&M resources (staff, materials, replacement parts, etc.) are included in the annual budgets. Studies of commercial buildings estimate potential O&M-related energy savings to be from 5% to 30% (Hunt and Sullivan 2002). Buildings designed for sustainability need to focus on maximizing savings through a proactive O&M program that focuses on operational efficiency.

One component of such a program is the periodic recommissioning of equipment, which involves rechecking and recalibrating the original equipment. Examples of typical O&M and recommissioning activities include calibrating sensors, checking/resetting temperature setpoints, maintaining proper building operating schedules, balancing/rebalancing the HVAC systems, changing filters, metering/submetering energy with analysis and followup action as appropriate, and training and certifying operators for building mechanical/electrical equipment and systems. PECI (1997) estimates $0.17/ft^2 as the average cost to recommission existing buildings. Applying this cost rate to the Federal building inventory and assuming a 10% resulting reduction in energy use yield a simple payback for recommissioning of 1.4 years for energy savings alone (Hunt and Sullivan 2002).

Case Study 2-2 demonstrates how significant energy was saved using many of the techniques just described, including energy-efficient mechanical equipment and commissioning.

[23] This is within the range of 5% to 30% estimated for savings associated with sound O&M. To estimate the cost reduction of $1310, the energy cost was assumed to have been 10% higher had no commissioning occurred, i.e., it would have been $11,800/.9 or about $13,100. A 10% savings, based on an original annual energy cost of about $13,100, is $1310.

Case Study 2-2: Facility at Sandia National Laboratories Reduces Energy Costs

This case demonstrates that a significant amount of energy can be saved by analyzing energy consumption using models and choosing technologies with favorable lifecycle costs.

Project Description: The 151,000-ft^2 Process and Environmental Technology Laboratory in Albuquerque, New Mexico, houses 180 people in a central core of labs with offices on the perimeter. By carefully considering cooling, heating, and process/electrical loads and revising the design, the team increased energy efficiency by over 20% between the preliminary and final designs.

Approach to Sustainable Design: The design for this building focused only on the energy aspects of sustainability. The efforts began when energy modeling during the first phase of the design process showed consumption that exceeded by 20% the average annual energy use of Sandia's most energy-intensive facilities. The design team evaluated a wide range of advanced energy-efficiency technologies using energy modeling and lifecycle cost analysis.

Sustainable Features: The largest energy consumer in the building is the ventilation air system that is required to maintain a safe laboratory environment; therefore, the laboratory HVAC system was a major focus of the redesign. Sustainable design features included in this building were variable-frequency drives for fan volume and pump control, a heat pipe energy recovery system with evaporative cooling, a chilled water thermal energy storage system, premium efficiency motors, a premium efficiency multiple boiler system, variable-air-volume fume hoods, energy management control systems (full direct digital control), sunshades and reflective glass, energy-efficient lighting, metering, and commissioning.

Financial Considerations: The table below shows the principal systems that added to first costs, the estimated cost savings, and simple paybacks. The total building cost was $28.5 million. The additional features described in the table added about 4% to the total cost but will quickly be returned in annual cost savings. Commissioning the building cost about $300,000 (about 1% of the building design cost) including internal staff time and the contractor's test engineers. After one year of operation, the annual energy consumption was 269,000 Btu/ft^2, which was even lower than the 341,000 Btu/ft^2 predicted by energy modeling studies.

Principal Systems Adding to First Costs and Estimated Cost Savings and Simple Paybacks

	Added Cost	Added Cost	Energy Savings	Energy Savings	Payback Period (yr)
Variable-frequency drives instead of inlet vanes for fan variable-volume control	109,600	726	61,700	259	1.8
Heat pipe energy recovery system with evaporative cooling	329,600	2182	31,800	211	10.4
Chilled water thermal energy storage system	239,500	1586	104,000	689	2.3
Premium efficiency motors	6,930	45	3,200	21	2.2
Premium efficiency, multiple-boiler system	8,750	58	8,200	54	1.1

Sources: Personal communication with R. Wrons, Sandia; and Laboratories for the 21st Century (2001).

2.3 Annual Water Cost Savings

Water efficiency can be achieved using a number of technologies that lower indoor water consumption (compared with the standard technologies available on the market), such as ultra-low-flow showerheads and faucet aerators, no-water urinals, and dual-flush toilets. Facilities can also lower potable water consumption by using nonpotable water for productive uses (e.g., using technologies that harvest rainwater or treat wastewater for re-use in various other applications in the buildings or on the site), better energy systems, recirculating water systems (instead of once-through cooling), leak detection and repair, and sustainable landscaping.

The costs for several water-saving features were estimated for the 20,000-ft^2 prototype building (see Table 2-4). All of the water-saving strategies analyzed have favorable economics, with payback periods from 2.8 to 0.3 years. If all the strategies in Table 2-4 were implemented, the total reduction in the annual cost of water for the building would be about $330, and the first-cost savings would be $590. These measures would reduce water consumption within the building by approximately 57%.

Table 2-4. Prototype Building Analysis: Cost Data for Water-Efficiency Features

	Incremental First Cost Per Unit	Incremental First Cost Per 1000 ft^2*	Annual Cost Savings Per 1000 ft^2*	Simple Payback (yr)
Ultra-low-flow showerhead	$4.99 per showerhead	$0.50	$0.33	1.5
Ultra-low-flow faucet aerators	$5.87 per faucet	$2.35	$8.14	0.3
Dual-flush toilets	$50.00 per toilet	$10.00	$3.58	2.8
No-water urinals	-$282 per urinal	-$42.30	$4.53	Immediate

* Costs were converted to a dollar value per 1000 ft^2 of gross building floor space to compare types of features. Cost values were rounded to three significant digits, although the convention of showing two numbers to the right of the decimal place (for cents) was maintained. Simple payback periods are shown in tenths of a year.

The following features were examined:

- **Ultra-low-flow showerheads and faucets.** The sustainable features examined in this study exceed the current standards required under EPAct. The current standards say showerheads cannot exceed 2.5 gallons per minute (gpm) at the typical building pressure between 40 and 80 pounds per square inch (psi). A more sustainable showerhead that uses 2.0 gpm was chosen for analysis in this document. Under current standards, kitchen faucets cannot exceed 2.5 gpm at 80 psi, and restroom faucets cannot exceed 2.2 gpm at 80 psi. For both the kitchen and restroom faucets, a 1.0 gpm model was chosen as the sustainable option for analysis in this document.
- **Dual-flush toilets.** Regulations mandate that toilets not exceed 1.6 gallons per flush (gpf). A dual-flush toilet has two flushing options: liquid flushing at 0.8 gpf and solid flushing at 1.6 gpf.
- **No-water urinals.** A no-water urinal that treats the waste chemically was compared with a typical water-using urinal.

Many Federal sites (military bases, national parks, U.S. Post Offices, and GSA buildings) have installed no-water urinals and other water-saving devices with great success. For example, the

North Island Naval Air Station in San Diego, California, installed over 200 no-water urinals, and the National Aeronautics and Space Administration's Jet Propulsion Laboratory in Pasadena, California, installed 250 units. The University of California, Los Angeles (2000) performed a study, examining the performance of a urinal that uses no water compared with a urinal that uses 3 gpf. The study compared the following parameters to determine how well the no-water urinal performed: usage, bacterial growth and odor, and lifecycle cost. The study concluded that the no-water urinal performed better than its specifications. In the tests conducted, no odors were detected.[24]

Many other water-saving approaches are available, including process-oriented technologies and site-specific techniques, for which costs are difficult to quantify generically as was done for the low-flow appliances described above. However, these measures are often very cost effective:

- **Cooling towers** are often one of the largest water users for large office buildings, hospitals, and industrial facilities. As water is evaporated through the tower, dissolved solids remain in the system and build up over time, requiring water to be purged from the system through what is known as "bleed-off." Maintaining water quality is key to saving water in cooling towers and reducing bleed-off. Chemical treatment, side stream filtration, and ozonation can help maintain proper water quality and reduce bleed-off and water consumption.
- **Single-pass cooling equipment** can also be a major water user in Federal facilities. When the equipment is modified to a closed loop system, the water can be recycled rather than discharged down the drain, saving up to 40 times the water required for heat removal from the equipment.
- **Boiler and steam systems** are often found in large Federal facilities such as central plants, hospitals, large office buildings, barracks, and industrial process plants. Proper maintenance of steam traps and condensate return and reduction of blow-down by maintaining proper water quality in the system can help reduce water use in these systems.
- **Leak detection and repair of water distribution systems** can provide large water savings with very quick payback, especially for military bases that have old (pre-1940s) systems. Such systems can reduce water losses and operating costs and can increase understanding of system operating characteristics. Typically, leak detection is done as part of a comprehensive water audit to help determine the source of unaccounted for water consumption at the site.
- **Sustainable landscaping** using plants native to a region (including drought-resistant plants) reduces (or eliminates) the need for irrigation water. This is discussed further in Section 2.4.

Case Study 2-3 discusses the water savings achieved at a facility in Ann Arbor, Michigan, by using closed-loop cooling and other measures. Although this example demonstrates savings in a retrofit situation, many of these techniques can be used in constructing new facilities, especially those housing laboratory or other process equipment with high water and energy needs.

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[24] The chemical cartridge (a device in the urinal's drain that traps odors while allowing urine to pass through) performed with no maintenance problems over 7,000 uses (the guaranteed number of uses for each cartridge) and did not clog during the testing period. The no-water urinal did not have a greater bacterial growth level than the conventional urinal. The study measured concentrations of ammonia, the chemical that produces the offensive odors in urinals. No significant difference existed between ammonia levels in the vicinity of the two urinals and neither approached the level that can be detected by humans. In a retrofit scenario, the economic analysis performed for the no-water urinal indicated a simple payback of less than three years and an annual internal rate of return from 37% to 61% (the range is based on population densities of different types of buildings).

Case Study 2-3: U.S. Environmental Protection Agency (EPA) Facility in Michigan Reduces Water Consumption by 80%

The National Vehicle and Fuel Emissions Laboratory underwent a major retrofit to reduce energy and water consumption using an Energy Services Performance Contract (ESPC).* The facility reduced its water consumption by 80% over baseline conditions, saving about $140,000 annually through a complete upgrade of the facility HVAC system, installation of chilled and hot water recycle loops, and use of other conservation measures.

Project Description: This water-intensive facility is a 30-year-old, 175,000-ft^2 building in Ann Arbor, Michigan, and is owned and operated by the EPA. The building houses offices, testing laboratories, and support spaces. The EPA, with support from DOE's FEMP, awarded an ESPC to NORESCO in 1998 for a comprehensive upgrade of the energy systems; this upgrade also significantly reduced water consumption and costs.

Approach to Sustainable Design: The building's main functional space is a high-bay research space where vehicles and engines are tested. Testing activities consume a high level of both energy and water. Before the retrofit, the facility had an annual utility bill of over $1 million, and annual water consumption averaged 31 million gallons from 1993 to 1995. During that time, single-pass cooling water (for the engine test cells, air compressors, and process chillers) accounted for about 75% of total facility water use. Cooling tower makeup water accounted for an additional 10% of the facility's water use.

The facility engaged in an ESPC with the following objectives: reduce energy consumption, emissions, and energy costs through energy conservation measures (ECMs); exceed Federal energy reduction mandates; eliminate chlorofluorocarbons (CFCs); reduce water consumption; and provide a simple payback of less than 10 years on the contractor's capital expenditure. Analysis and audits resulted in 11 individual ECMs. Although most of the ECMs focused on energy savings, many of the energy-savings measures also significantly reduced water use. One ECM specifically focused on water conservation by converting once-through cooling systems to closed-loop systems, recirculating chilled water to cool process loads at the facility, and significantly reducing water consumption.

Sustainable Features: Key components of the ESPC included replacing 36 rooftop air-handling units; replacing existing equipment in the central heating and cooling plant with two new direct-fired chiller-heater absorbers, one new high-efficiency condensing boiler, and two new cooling tower cells with variable frequency fan drives; and adding a new pumping system. The upgraded chilled water system was sized to replace the once-through cooling water with recirculated chilled water.

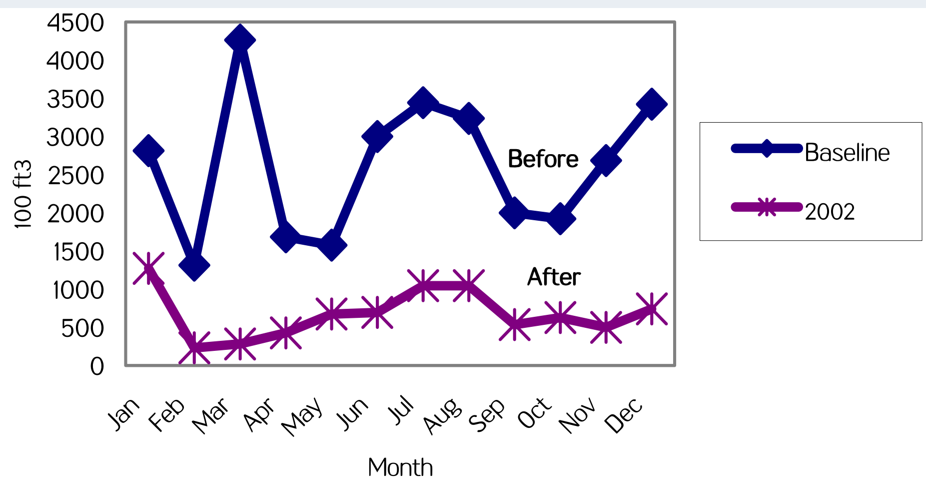
Before the ESPC, the single-pass cooling system used about 23 million gallons of water per year; the upgraded cooling plant with the recirculated chilled water loop reduced water consumption by over 95% to fewer than 1 million gallons. In addition, before the ESPC, boiler makeup water accounted for about 1 million gallons of facility water per year; but after replacing the old system with high-efficiency condensing boilers and installing a new hot water piping distribution system, the hot water loop makeup now accounts for only 7200 gallons of water per year. In addition to the ESPC, the facility has used other water-saving best management

*An ESPC is a contracting method that allows a contractor (instead of the building owner) to incur the cost of implementing energy savings at a facility. The contractor is paid back during the term of the contract from a share of the energy savings resulting from the measures that were implemented.

practices, including public information and education programs to educate employees on water conservation topics, audits for leak detection and repair, a water-efficient landscape that uses no irrigation water, and low-flow fixtures and faucets.

Financial Considerations: The figure below shows water consumption before the measures were implemented (averaged over 1993 to 1995) and after the implementations (in 2002). About 25 million gallons (3.3 million ft^3) of water were saved annually. Because water and sewer costs, combined, are about $4.20 per 100 cubic feet in Ann Arbor, the measures reduced total water and sewer costs by about $140,000 annually. Associating a precise capital cost directly to this annual water cost savings is difficult because of the synergy between the energy and water savings. For example, the ESPC replaced 36 rooftop air-handling units that, before the retrofit, operated in a single-pass mode. The new units use enthalpy recovery wheels and recirculate 80% of the air. This change reduced water consumption because central plant heating and cooling requirements have been dramatically reduced. This reduction created the opportunity to replace the cooling tower with two smaller cells, significantly reducing water use in the tower. In addition, the plant no longer has to humidify single-pass air in the winter.

The ECM that was directly related to water reduction (implementing the recirculating chilled water loop) cost about $129,000 in first costs and saved over $48,000 in water costs in 2002. If these savings are achieved each year, the payback period will be 2.7 years.



Water Consumption Before and After ECM Implementation

Sources: Personal communication with S. Dorer, Facility Manager at the National Vehicle and Fuel Emissions Laboratory, Ann Arbor, Michigan; R. Sieber, ERG (consultant); and P. Wirdzek, EPA Labs21 Program Manager.

2.4 Lower Costs of Facility Maintenance and Repair

Sustainable design aims to increase durability and ease of maintenance. For example, the service areas within sustainable buildings should be designed with enough space to allow easy access to mechanical equipment. Easy access will reduce the cost of scheduled maintenance, repair, and eventual replacement. Other approaches can also reduce annual maintenance costs using sustainable design:

- Using durable, long-lasting sustainable materials can decrease maintenance and repair costs. For instance, cement companies have tested fly ash and slag concretes and found that, if properly cured, they have greater strength and durability than concrete made from normal Portland cement.[25]
- Using low-emitting paints offers excellent durability according to some vendors.[26]
- Designing buildings with areas for efficient and convenient collection of recyclable materials, such as paper, plastic, and glass, can reduce annual waste disposal costs (if recycling costs are lower than normal charges for municipal solid waste).
- Using fluorescent lamps reduces labor costs for maintenance. These lamps last about 10,000 hours as opposed to 1,000 hours for incandescent lamps. Therefore, about 10 lamp changes (and the associated labor costs) are avoided by using fluorescent lamps.
- Lightening roof color can prolong a roof's lifetime (in addition to reducing summertime heat gains and air conditioning costs) (Rosenfeld et al. 1995).
- Using recycled carpet tiles, which can be removed and replaced individually, reduces the need to replace carpet.
- Using sustainable landscaping techniques typically decreases lawn mowing, fertilizer use, and irrigation and has short payback periods (e.g., in the prototype building example below, the payback was less than one year).
- Managing stormwater through "natural" methods such as drainage ponds that also serve as habitats for wildlife, rather than storm sewers, often exhibits favorable lifecycle costs.

Table 2-5 shows the first costs and annual cost savings of two specific site-related strategies that reduce annual maintenance costs using the same prototypical building described in the previous sections. Together, the strategies increase first costs by about $5600, which is quickly repaid through maintenance cost savings of about $3600 annually.

Table 2-5. Prototype Building Analysis: Costs for Sustainable Siting Features

	Incremental First Cost	Incremental First Cost Per 1000 ft^2*	Annual Cost Savings Per 1000 ft^2*	Simple Payback (yr)
Sustainable stormwater management	$3140	$157	$28.20	5.6
Sustainable landscape design	$2449	$122	$152	0.8

* Costs were converted to a dollar value per 1000 ft^2 of gross building floor space so types of features could be compared. Multiply costs per 1000 ft^2 by 20 to obtain total costs for the building. Cost values were rounded to three significant digits, although the convention of showing two numbers to the right of the decimal place (for cents) was maintained. Simple payback periods are shown in tenths of a year.

[25] For example, see http://www.lafargenorthamerica.com/lafargeNA.nsf/CementSplash?OpenForm.
[26] For example, see http://www.duron.com/products-generalinfo-interior-genesis.html.

The two site-related strategies shown in Table 2-5 are described as follows:

- **Sustainable stormwater management.** An integrated stormwater management system combines a porous gravel parking area with a rainwater collection system, where rainwater is stored for supplemental irrigation of native landscaping. This porous, gravel-paved parking area is a heavy load-bearing structure that is filled with porous gravel, allowing stormwater to infiltrate the porous pavement (reducing runoff) and to be moved into an underground rainwater collection system. The water can be used to supplant fresh water from the public supply for uses that do not require potable water. This sustainable system is compared to a conventional asphalt parking area and a standard corrugated pipe stormwater management system without rainwater harvesting.
- **Sustainable landscape design.** A mixture of native warm weather turf and wildflowers is used to create a natural "meadow" area. This strategy is compared with traditional turf landscaping of Kentucky blue grass, which requires substantially more irrigation, maintenance, and chemical application.

Although the particular sustainable stormwater system used for the prototype increases the total construction cost by a little over $3000 (about 0.1% of total building construction cost), it saves over $500 annually in maintenance costs because less labor is required for patching potholes and conducting other maintenance on an asphalt lot. The resulting payback period is less than six years. The sustainable landscaping approach shows even more favorable economics; the incremental first cost is nearly $2500, but this is repaid in less than one year with an annual O&M costs savings of $3045 in avoided maintenance, chemical, and irrigation costs. (See Appendix D for more information on how these costs were calculated.) Case Study 2-4 shows a real-world example of the cost savings associated with sustainable landscaping.

2.5 Lower Churn Costs

In today's work environment, employees are increasingly relocated within existing buildings to improve organizational effectiveness or as a result of downsizing, reorganization of the business, or business growth. A survey conducted by the International Facility Management Association (IFMA) and published in 1997 determined that, on average, 44% of building occupants move within a given year. This is called the "churn rate."[27] In government buildings, the churn rate appears to be somewhat lower – 27%. (The survey included 20 government respondents.) The survey found that the churn rate has been increasing over time.

Moves are expensive. According to IFMA (1997), the average move in the government cost $1340 (per person). The cost of a move depends on the extent to which the facility must be modified to accommodate the changes. IFMA found that if new walls, new or additional wiring, new telecommunications systems, or other construction is needed to complete the move, the average cost in a government setting is $3640 (IFMA calls this a "construction" move). However, if no furniture is moved, no wiring or telecommunication system changes are required, and only files and supplies are moved, the average cost in a government building dropped to $166 (IFMA calls this a

[27] The churn rate is defined as the total number of moves made in a 12-month period, divided by the total number of occupants, multiplied by 100 (to obtain a percentage).

Case Study 2-4: Argonne National Laboratory's Central Supply Facility Reduces Costs Through Sustainable Landscaping

This case study demonstrates how native landscaping can reduce both installation and O&M costs of landscaping a Federal facility. The cornerstone of this design is the native trees, which require no irrigation system, provide shade to the building, and require very little maintenance compared with a traditional landscape of sod and large non-native trees.

Project Description: The facility – built in 2001 in Argonne, Illinois – is Argonne's shipping and receiving warehouse. It was built onto an existing structure.

Approach to Sustainable Design: The design and integration team for the facility began incorporating design review early to ensure that all technical aspects were properly evaluated. Other aspects vital to the project's success included educating the building occupants about sustainable features and training the maintenance staff.

Sustainable Features: Argonne incorporated many sustainable design features into the facility. One hundred immature native trees were planted in small groups surrounding the facility. The trees were much smaller than the larger mature trees traditionally planted on Argonne grounds. Planting smaller trees helps reduce both the stress on the trees at planting and their long-term water requirements. Native turf was seeded on the grounds instead of planting traditional sod, thereby eliminating the need for an irrigation system.

Other sustainable features included recycled building materials such as concrete block, carpet, structured steel, lumber, ceiling tiles, partitions, and gypsum board. In addition, efficient water fixtures in the restrooms, low VOC paint, an energy-efficient mechanical system, high-performance windows, and a rooftop rain catchment system were integrated in the sustainable design. The facility was LEED-certified in spring 2002.

Financial Considerations: The native landscaping significantly reduced installation and O&M costs. Installation costs were reduced because smaller holes were required to plant smaller trees. The 100 native trees that were planted on the grounds had the same estimated cost as 40 mature trees. Seeding native grass on the grounds was a much less labor-intensive practice than laying sod. Sod also requires large amounts of water to saturate the ground so the sod can adapt to the new environment. Seeding with native grass and eliminating the irrigation system saved Argonne about $11,000 in first costs.

In one growing season, the trees and seeded grass became well established and currently do not require supplemental water to remain healthy. If large non-native trees and sod had been used, regular watering would have been required for two growing seasons and supplemental water would have been required during droughts. The native landscaping reduced water requirements by an estimated 40% within the first two growing seasons and reduced the need to mow and fertilize the native grass. Overall, the native landscape reduces O&M costs by an estimated 50% compared with more traditional landscape.

Sources: Personal communication with K. Trychta, Argonne's Pollution Prevention Coordinator.

"box" move).[28] If existing furniture is reconfigured or furniture is moved or purchased but only minimal telecommunication reconfiguration is needed, the government cost averaged $613 (a "furniture" move).

To reduce churn costs, many high-performance, sustainable buildings include a raised floor system that creates an underfloor plenum used for HVAC air distribution and modular power cabling and telecommunications/data systems. The HVAC system and cables in the underfloor plenum typically are accessible through individual, movable floor tiles. These raised-floor systems also enable personal controls to be used, allowing each occupant to control the level of ventilation, temperature, and lighting levels at his or her own workstation (the benefits of personal controls on occupant productivity, health, and well-being are discussed in Section 3). In addition, sustainable buildings often use removable partitions in place of permanent walls.

> *When using underfloor air systems, local workstation air conditioning control devices can be relocated in less than five minutes with a screwdriver being the only tool required.*
>
> Source: Shute (1992)

Using raised floor systems and removable partitions can significantly reduce churn costs. No ductwork revisions or other complex construction is needed to alter workstation configurations. The access floor system, together with floor diffusers, allows the layout of the space to be modified with very little lost work time. The move costs in a building with a raised floor and movable partitions would be closer to the box or furniture moves described above ($166 to $613 per person) than to the construction move ($3640 per person).

The first costs of a building with a raised floor system and underfloor HVAC/cabling will depend on the many factors specific to the building, but estimates documented by Loftness et al. (2002) indicate that the first costs are about the same as (or only slightly higher than) those in a building with a traditional acoustical tile or drywall ceiling system.[29] The major additional cost of such a building is the raised floor itself – from $3 to $10/ft^2 depending on manufacturer, quality, and integrated components (Loftness et al. 2002) compared with installed acoustical ceiling tile, which typically costs $1.49 to $2.31/ft^2 (RS Means Company, Inc. 2002). However, the additional costs for the raised floor would most likely be offset by a lower first cost of the underfloor air-handling system compared with the traditional ceiling air-handling systems. Milam (1992) states, "Most HVAC equipment installation occurs below the raised floor, therefore laborers perform little work on ladders, platforms, or hoists. . . . This allows substantial increases in laborer productivity that corresponds to savings in labor costs." These underfloor air-handling systems also usually have smaller piping, pumps, and refrigeration equipment; and most of the ductwork is eliminated.

In addition to HVAC savings, the underfloor system also reduces first costs of power distribution, receptacles, data communication devices, and labor for installing cabling. Some evidence exists

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[28] Using the entire population of buildings surveyed by IFMA (1997), including various types of private-sector enterprises, the average cost per move was $1207; the average cost of a construction move was $4194; the average cost of a box move was $149; and the average cost of a furniture move was $523.

[29] One study (Wilson 1998) of a private-sector office building in California estimated a $2.70/ft^2 *decrease* in first cost for the access floor system (compared with an overhead system). Part of the estimated cost reduction in this study was from using carpet tiles in the building with the access floor versus rolled goods in the traditional building, which decreased the cost of the access floor by almost $100,000. However, given that the traditional building could also use carpet tiles, the cost differential of $2.70 seems somewhat overstated. If the carpet difference were eliminated from the estimate, the cost of the building with the access floor would have been about *equal to* that of the standard ceiling HVAC distribution system. Thus, even though these data do not necessarily show that the access from system is less expensive than an overhead system, the data do indicate that the differences in cost between the two kinds of systems are negligible.

that underfloor HVAC systems also reduce annual energy costs by 20% to 35% (Loftness et al. 2002). See the comprehensive report by Loftness et al. (2002) for a complete explanation of the costs and benefits of these underfloor systems. In addition to churn cost savings, the use of underfloor systems and movable partitions also saves materials and material costs during moves.

For the prototype 20,000-ft² office building, which hypothetically houses about 100 occupants, building owners could save from $35,000 to $81,000 in churn costs[30] if the building were outfitted with an underfloor system and moveable wall partitions instead of traditional systems. These savings likely could be achieved with little additional first cost.

> *"The cost of an intelligent building with a good quality access floor, a modular electrical distribution system and under-floor air is very close to the cost of a traditional poke-through building (less than 1% greater)."*
>
> Source: York 1994 (cited in Loftness 2002)

Research Summary 2-1 provides data on churn costs in an actual government office building with 1,500 work stations (the Rachel Carson State Office Building in Harrisburg, Pennsylvania). This study indicates that a high-performance green building with a raised floor could save over $800,000 annually (compared with one without the raised floor) in a large building that has a 25% annual churn rate (a savings of $2250 per person moved). The costs of churn are often neglected when the lifecycle costs of a building are estimated. This evidence indicates that such costs should be more seriously considered.

2.6 Lower Absenteeism and Improved Productivity

Many studies, which will be described in this section, have shown that building occupants respond to some of the features of sustainable buildings by working more productively, making fewer errors, and being absent less often, thus reducing labor costs.

Figure 2-1 shows that, as a fraction of total expenditures, labor costs in the government far exceed construction, energy, or other annual costs,[31] so measures that positively influence worker performance and absenteeism rates could have a much higher financial impact than energy efficiency or other measures affecting operating costs.

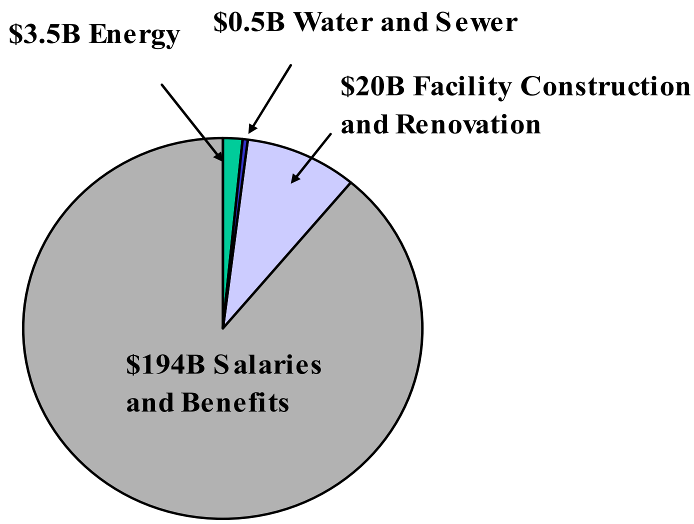

Figure 2-1. Annual Federal Government Costs

[30] These figures assume 27 moves at a savings per person of about $1300 (the difference between the average government move and the box move) to $3500 per move (the rough difference between a construction move and a box move). Although Loftness et al. (2002) estimate somewhat lower cost savings of $100 to $500 per move, the cost savings of $2250 per move estimated for the case study of the Rachel Carson State Office Building is at about the midpoint of the estimated range used in these figures.

[31] Sources for data in Figure 2-1 include Office of Personnel Management website http://www.opm.gov/feddata/02factbk.pdf and Federal Facilities Council (2001). Note that personnel costs are for civilians only (including civilian employees of U.S. Department of Defense). Energy and other costs include military facilities.

Research Summary 2-1: Pennsylvania's Department of Environmental Protection Estimates the Cost of Churn

The Pennsylvania Department of Environmental Protection (DEP) took advantage of its need to relocate 700 of the 1500 employees in the Rachel Carson State Office Building (RCSOB) in Harrisburg, Pennsylvania, to estimate the cost of churn. The actual cost of the moves in RCSOB, which did not have a raised floor system, was compared with the estimated churn cost in a new high-performance "green technology" office – South Central Regional Office Building (SCROB) – where employees had similar functions and space requirements. The comparison shows that using raised floor systems in sustainable buildings can reduce churn costs by 90%.

Research Team: Staff members of the Pennsylvania DEP; J. Toothaker, Lead.

Research Setting: The RCSOB is a traditional 16-story office structure with a central service core. It is equipped with carpet tile, a cellular floor for electrical and telephone/data distribution, modular furniture, full-height demountable walls, and mechanized central file systems on all floors. However, it does not have a raised floor. Its dropped ceiling contains drop-in fluorescent light fixtures, sprinklers, and a variable-air-volume HVAC ceiling distribution system; the building also has a hot water perimeter heating system. Exterior walls are glass, and the central core provides restrooms, elevators, electrical rooms, telephone/data rooms, and communicating stairways on each floor.

The opportunity to study churn costs in this building resulted from a requirement to reconfigure and relocate 700 of the 1500 employees in this facility to reorganize one agency into two agencies. Workstations and common areas had to be reconfigured. Two floors were completely reconfigured to accommodate about 240 work areas, with the remaining 460 workstations scattered throughout the remaining twelve floors. This involved the following:

- Dismantling and reconstructing private offices
- Unwiring, cleaning, and reconfiguring the modular furniture and cleaning the chairs
- Reconfiguring variable-air-volume boxes, lights, and sprinkler heads in the ceilings
- Reconfiguring central file equipment and the electrical and telephone/data connections on each floor
- Cleaning or painting all surfaces in the reconfigured areas
- Relocating personal computers and peripherals.

Components within the SCROB's Raised Floor System

The photo shows the plenum space below the floor surface and the air diffuser, phone modem/fax mounting, and power strip on top of the carpet tile.

All of this work was done using competitively bid contracts, with about 50% of the labor performed at straight time during the workday and the remainder at premium pay at night and on weekends.

DEP had just completed SCROB, a high-performance "green technology" office with a raised floor system. This project allowed the team to compare churn costs between the two types of offices. The primary difference in the churn costs between the two buildings is the use of a raised floor system to create a floor plenum for HVAC air distribution, which also houses the modular power and telephone/data distribution systems. This raised floor plenum system with its individual floor tiles, which are movable and easy to relocate, allows easy access to the floor HVAC diffusers and power telephone/data cables. When the raised floor system is used, systems furniture and demountable walls are no longer wired together, which further reduces cost and lapse time for churn.

Methodology: The comparative evaluation consisted of a methodical review of the actual unit costs and elapsed time needed for each contracted activity for the RCSOB moves. Then, the DEP estimated the cost and time needed for each of the same activities for a comparable move in the SCROB.

Results: The cost for the RCSOB project, which reconfigured 700 workspaces (including both offices and open workstations) was about $1.777 million or $2538 per person. The project's actual renovations and reconfigurations were completed in about three months.

DEP conducted a detailed analysis of the move costs, including all materials and labor for each contracted activity. Each contracted activity in the new building with the raised floor (SCROB) was estimated. The cost and length of time to physically reconfigure work spaces were estimated to be about 90% lower in SCROB than in RCSOB. The table below shows the calculations (for ease of presentation, numbers and percentages were rounded).

Comparison Analysis of the Moving Costs in RCSOB

	Actual Costs in the RCSOB	Hypothetical Costs Had A Raised Floor Been Installed in RCSOB
Building type	Conventional office facility	High-performance green building (raised floor)
Number of work spaces	1500	1500
Annual churn rate	25%	25%
Number of work spaces reconfigured annually	375	375
Cost per reconfiguration	$2,500 (based on actual data)	$250 (estimated based on situation in SCROB)
Annual cost of churn	$937,500	$93,750
Churn cost savings	Not applicable	$843,750

The RCSOB was completed in 1993 at a constructed cost slightly over $40 million. If the facility had been designed and built with a raised floor, lower churn costs equal to over 2% of its constructed cost per year could have saved DEP about $7.6 million since the building's occupancy in 1993.

Source: Personal communication with J.S. Toothaker, former Bureau Director, DEP, Commonwealth of Pennsylvania. Mr. Toothaker managed the 700-employee move in the RCSOB and compared the actual and estimated costs between the two facilities based on his personal participation and knowledge of the facilities. Mr. Toothaker was the principal developer of the Building Green in Pennsylvania Program.

One key research study (Milton et al. 2000) that examined the relationship between absenteeism and ventilation rates is highlighted in Research Summary 2-2. This study assigned dollar values to the benefits of better ventilation and estimated potential annual cost savings of about $25,000 per 100 employees, resulting from a one-time investment in better ventilation systems of $8000 per 100 employees. This research strongly implies that designers should pursue the goal of good indoor air quality simultaneously with the goal of energy efficiency.

Research Summary 2-2: Improved Indoor Air Quality Reduces Absenteeism Costs

A research study assessed sick leave for 3720 hourly workers in a large manufacturing firm in Massachusetts to determine the relationship between absenteeism and factors such as ventilation, humidity, and indoor air quality. The study showed that $24,444 per 100 employees could be saved annually with a one-time investment in improved ventilation of $8050 per 100 employees.

Research Team: The research team included D.K. Milton of the Harvard School of Public Health, P.M. Glencross of the Harvard School of Public Health and Polaroid, and M.D. Walters of Polaroid.

Research Setting: The research setting was 40 buildings and 115 independently ventilated work areas.

Methodology: Sick leave data were gathered from corporate records (excluding extended sick leave or short-term disability). Other data gathered on employees included age, gender, race, shift, job code, years of employment, and the employee's primary work area (building and floor).

The final analysis focused on clerical workers to control for the potential effects of occupational factors. The analysis also used existing corporate records to identify building characteristics and indoor environmental quality complaints. The study gathered the following data on each building in the study:

- Presence of devices to humidify supply air such as steam, spray, and finfill humidifiers
- Formal complaints to the corporate environmental health and safety office and remediation efforts
- Ventilation ratings for each floor – categories as either "moderate" (about 12 L/s) or "high" (about 24 L/s)
- Additional air quality data, including endotoxin and total airborne bacteria counts, culturable bacteria, culturable fungi, spore counts, and VOCs.

Key Findings: The study's results included the following:

- Moderate ventilation and use of humidifiers were associated with more total sick leave as well as more short-term sick leave.
- Of the short-term sick leave, 35% was attributed to lower ventilation rates, translating to 1.2 to 1.9 days of increased sick leave per person per year.
- Reductions in sick leave from improved ventilation were similar to reductions during flu season due to influenza vaccination.
- Respiratory illnesses caused by airborne viruses or bacteria could be effectively reduced with ultraviolet irradiation of air near the ceiling and with increased ventilation.
- Economic analysis showed that investing $8050 per 100 employees in improved ventilation could reduce sick leave by $24,444 per 100 employees (from $39,950 to $15,506, per 100 employees).

Source: Milton et al. (2000).

Another study of 11,000 workers in the Netherlands found that absenteeism from "sick building syndrome" is likely to be 34% lower when workers have control over their thermal conditions (Preller et al. 1990). A comprehensive study of methods to improve indoor environmental conditions estimated that the value of improved productivity (including lower absenteeism) of office workers could be as high as $160 billion nationwide (Fisk 2000).

Measuring productivity is relatively straightforward for simple information processing tasks, such as data entry and forms processing. For most knowledge workers, however, productivity is more difficult to measure because the outcomes are highly variable, often elusive, and difficult to document.[32] Furthermore, much knowledge work is valued for its impact rather than its output. "Impact" refers to the value of the work (as indicated by an idea, concept, plan, or policy) to the organization. Because of these difficulties, the building blocks or precursors of productivity are often measured rather than work output. These blocks or precursors include specific kinds of tasks associated with knowledge work performance, such as attention, reading comprehension, creativity, and logical thinking.

Performance benefits resulting from sustainable building features are described below. The evidence presented on performance benefits is drawn primarily from research conducted on occupants of actual buildings rather than from laboratory studies. The studies cited are from peer-reviewed publications or conference proceedings and include publications in building science, lighting, environmental psychology, and human factors. Taken as a whole, the studies show a cluster of building factors associated with improved performance: good ventilation; glare-free lighting; personal control over temperatures and ventilation; and good maintenance and cleaning, especially of the HVAC system. These factors appear to influence performance by reducing illness symptoms that interfere with work, by increasing alertness and reducing fatigue, and by reducing visibility problems.

- **Performance on clerical and word processing tasks.** Much of the research on work performance has been conducted in experimental settings where stimuli can be carefully controlled, although a few studies have been conducted in actual work settings. For example, a field simulation study tested performance on a word processing task in an office with and without a 20-year-old carpet (Wargocki et al. 2000). The study found that workers' performance was 6.5% better without the carpet. All other factors, such as ventilation and temperatures, were held constant. Therefore, the results are due to air quality differences associated with the old carpet. A frequently cited field study (see Research Summary 2-3) conducted in an insurance agency building found a 16% increase in performance on forms processing when the company moved into a new building (Kroner et al. 1992). The measure was actual work productivity, not performance on simulated tasks. Of the overall 16% increase in productivity, 3% was attributed to using personal controls over temperature and ventilation and 13% was attributed to generally improved building quality and interior design, including improved daylight, views of a natural landscape, better access to windows by workers, and increased visual openness of the environment. In a review of building studies, Wyon (1996) estimated that providing workers with temperature control of just three degrees (plus or minus) would result in productivity increases of 7% for typical clerical tasks.

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[32] In some cases, researchers have attempted to associate a dollar figure on the absenteeism and other occupant benefits. The Center for Building Performance and Diagnostics within the School of Architecture at Carnegie Mellon University has collated a large body of research into a tool called the Building Investment Decision Support. This tool allows a user to generalize the results of a particular research studies to estimate potential dollar benefits at the user's facility.

Research Summary 2-3: Personal Environmental Controls at West Bend Mutual Insurance Company Improve Worker Productivity

This study assessed the impact of workstation personal controls and other features typically associated with sustainable buildings on worker productivity using an existing performance monitoring system. When the organization moved into the new building, overall productivity increased by 16%. Of that, 3% was associated with the system that provided personal control over temperature, air velocity/direction, task lighting, and sound masking.

Research Team: Rensselaer Polytechnic University.

Research Setting: The research took place in an existing building and a new building that had personal controls at most of the workstations.

Personal Control System

Features of the Old Building:

- 61,800 ft^2 for 400 workers (considered crowded)
- No task lights; ceiling lights were 4-ft recessed fluorescent fixtures
- Three different air distribution strategies
- Located in the center of town
- Managers located along window wall; workers in central core.

Features of the New Building:

- 149,800 ft^2 for 400 occupants and many amenities (conference rooms, instructional rooms, auditorium, cafeteria, exercise room, and outdoor patio)
- Skylights
- Indirect lighting
- 370 workstations with personal control over temperatures, air velocity and direction, task lighting. and sound masking
- 92% of workers on the perimeter with access to daylight and views (versus 30% in old building)
- Location in a prairie landscape setting with trees and a pond.

Methodology: Data were gathered for workers in the accounting and underwriting departments for 27 weeks before they moved into the new building and 51 weeks after the move. Data included the number of files of each type that each employee processed during the week. To separately account for the effect of the personal controls (versus the potential impacts of other building or organizational changes), components of the control system were randomly disabled during the last 24 weeks of the study – air velocity, air temperature, and the radiant panel.

Key Findings: The study's results included the following:

- The combined effect of the new building and the personal controls produced a median increase in productivity of about 16%. Personal controls accounted for a 3% increase and the new building and setting accounted for 13%.
- Overall satisfaction increased from 46% in the old building to 75% in the new building.
- Satisfaction with the new building's temperatures, air quality, noise, and lighting all improved.

Sources: Kroner et al. (1992).

- **Attention and concentration.** Studies have also found that certain sustainable design features improve performance on tasks requiring high levels of attention. For instance, a study by Nunes et al. (1993) found performance increases from 7% to 30%, depending on the task. The variability in performance was attributed to differences in ventilation levels and the consequent impact on illness symptoms. Lower levels of ventilation were linked to higher reports of symptoms, which in turn were associated with poorer performance. Workers reporting symptoms worked 7.2% slower on a vigilance task and made 30% more errors on a digit substitution task.

  Numerous studies show performance problems from increases in noise distractions and interruptions (Fried et al. 2001; Jones and Norris 1992). Decreased performance is more likely for complex, creative tasks and tasks relying heavily on short-term memory, such as writing and computational work. Many of the factors that increase noise distractions (e.g., smaller workstation sizes, increased densities, and reduced use of carpeting or other sound-absorbing materials) are commonly used to achieve sustainable goals such as increased access to daylight and views and improved flexibility. Therefore, sustainability-oriented designers should consider both positive and negative impacts of various design features in the final design.

- **Complex cognitive performance.** Improved performance on logical thinking tasks has also been reported in a review of interior environmental quality (Wyon 1996). Wyon cites studies in Sweden showing a 2.7% increase in logical thinking associated with personal control over temperatures. The impact of temperature conditions on performance is complex, with some studies showing improved performance on creativity and memory tasks with slightly elevated temperatures and with the opposite shown for concentration and logical thinking, which may benefit from slightly cool temperatures (Wyon 1996).

- **Organizational level performance.** Most productivity studies focus on individual level work. However, there is evidence that building design can influence high-level organizational outcomes. An analysis of the Total Quality Management (TQM) metrics data used by Herman Miller to assess its performance shows small increases of 0.22% in overall productivity and increases of 1% to 2% on other indicators after the organization moved into a new sustainable building (Heerwagen 2000). (This study is described in Section 3.2.)

- **Self-ratings of productivity.** Research in office settings often resorts to employees rating their own productivity (i.e., self-rating) because of the difficulty of obtaining actual work outputs. Although self-measures tend to be overestimated, when the measure is used in a comparative manner to assess responses to baseline environments and change initiatives, they provide useful information (Leaman and Bordass 2001). They also are fairly easy to administer.

  Studies using self-assessments of productivity have found strong relationships to thermal and air quality factors in line with studies of actual performance, as noted above. In a review of occupant surveys over a 20-year period in the United Kingdom, Leaman (1999) reports that comfort and perceived productivity are greater in buildings where occupants have more control over the environment and in mixed-mode buildings that have both natural ventilation and air conditioning. Two studies of more than 11,000 workers in 107 buildings in Europe also found increases in perceived productivity in buildings that provided workers with control over temperature and ventilation conditions (Preller et al. 1990).

  Similar results are reported for an intervention study in Canada (Menzies et al. 1997). The study consisted of two groups of workers in a mechanically ventilated building. The "intervention" group was given control over the ventilation at the workstation with a handheld infrared device that could regulate the amount and direction of air flow from four-inch air outlets in the ceiling. The "control" group was not given any control over ventilation. Workers in the intervention group said their productivity increased by 11% at 16 months after the study. In contrast, workers in the control group said their productivity decreased by 4%. Environmental assessments of the two spaces showed that air velocity in the intervention space tripled and that both temperature and ventilation variability across the space increased also (an indication that workers were making adjustments according to their personal preferences and needs).

A field study of electric lighting systems found increased self-ratings of performance with indirect lighting due to decreased glare on computer screens as well as reduced eye problems (Hedge et al. 1995).

2.7 Other Economic Benefits to the Building Owner

Federal agencies, as well as sustainable building owners in the private sector, are likely to accrue economic benefits as a consequence of a sustainable facility's environmentally and socially conscious image and its positive impacts on building occupants, prospective employees, the community surrounding the facility, and society as a whole.

Research has been conducted on a few important topics related to sustainable buildings, from which inferences can be drawn about the building owner's economic benefits, which are sometimes less direct and/or longer term than the benefits described in Sections 2.1 through 2.6. This section discusses several of these somewhat indirect or longer-term economic benefits:

- Better worker retention and recruitment
- Lower cost of dealing with complaints
- Decreased risk, liability, and insurance rates
- Greater building longevity
- Better resale value
- Ease of siting
- Strategic and economic value of an improved image.

2.7.1 Better Worker Retention and Recruitment

The environmentally conscious image associated with an agency that builds or occupies sustainable buildings may result in employee pride, satisfaction, and well-being that translate into reduced turnover, improved morale, and a more positive commitment to the employer. These effects may have a big financial impact by reducing labor replacement and training costs. In addition, these effects transfer to the building owner a reputation as a desirable employer, which in turn creates valuable leverage for attracting, recruiting, and retaining talented employees. Moreover, developing a high-caliber workforce ultimately results in additional long-term performance benefits described above. While rigorous statistical studies on employee retention and attraction in sustainable facilities have not been conducted, many studies have shown increased feelings of well-being associated with sustainable buildings (see Section 3.2). The retention and attraction aspects are a logical (although not fully proven) extension of feelings of well-being.

In his recent book, *The Sustainable Advantage*, Willard (2002) argues that sustainability, as a corporate strategy, will become more common if it can be linked more convincingly to business value. As Willard argues, organizations that make sustainability a core value may benefit by being able to attract and retain young workers who also value the environment and who will therefore be more willing to work harder to ensure that the organization's environmental values are realized. Willard also acknowledges that the work environment itself may influence attraction, retention, and productivity by creating better working conditions.

2.7.2 Lower Cost of Dealing with Complaints

When building occupants are uncomfortable – typically from a room temperature that is too hot or too cold – building maintenance engineers spend hours dealing with complaints. In a study of the costs of dealing with discomforts, researchers estimated that efforts to increase comfort could decrease the labor costs of responding to complaints by 12% (Federspiel 2001). The data from the study show that it takes 1.4 hours on average to diagnose a hot complaint and 1.7 hours to diagnose a cold complaint. The data also suggest that complaints are not due to differences among individuals, but rather to HVAC faults or poor control performance. Sustainable buildings that have well-designed HVAC and control systems that have been commissioned are less likely to experience these problems.

Another study reports that personal controls for HVAC systems reduce complaints to as low as 10 calls per 1000 employees per year (Loftness et al. 2002). (Those controls can be installed only in conjunction with underfloor air distribution systems.)

Less time dealing with complaints leads to more time to complete preventive maintenance tasks, increasing equipment longevity and lowering operating costs overall.

2.7.3 Decreased Risk, Liability, and Insurance Rates[33]

Building owners and operators face a wide range of risks (described below), which are particularly disruptive and costly in mission-critical governmental activities (civilian or military). Those risks may be partially mitigated by sustainable building design.

- **Property loss prevention.** Various green-building technologies reduce the likelihood of physical damages and losses in facilities (American Insurance Association 1999; Vine et al. 1998 and 1999; and Mills 2003b). For example, sustainable siting reduces the likelihood of property damage from flooding, mudslides, and soil subsidence. Efficient thermal envelopes and reduction in losses from recessed lighting or thermal distribution systems located above ceilings reduce the risk of ice-dam formation on roofs. Using efficient torchiere light fixtures eliminates the fire risk posed by halogen versions.
- **Business interruption loss prevention.** Unplanned power outages and improperly designed or maintained HVAC systems can cause temporary closure of facilities, resulting in disruption of operations and relocation costs (Brady 1995; Eto et al. 2001; and Mills 2001). These business interruption risks can be reduced by using onsite energy generation resources and energy-efficiency features.
- **Hedge against energy price and cost increases.** Energy is a significant part of facility operating costs. The likelihood of budget overruns from unanticipated energy price spikes can be reduced by energy-efficient design that lowers overall consumption.
- **Natural disaster preparedness and recovery.** Various energy-efficient and renewable technologies make facilities less vulnerable to natural disaster events, such as heat catastrophes, which are a particularly high risk for federally operated low-income housing (Deering and

[33] Dr. E. Mills of Lawrence Berkely National Laboratory contributed portions of this section.

Thornton 1998; Mills 2003a). Well-insulated attics, natural ventilation, and heat-reflective roofing materials can considerably reduce indoor temperatures during heat waves, averting hospitalization or loss of life. Using multipane (e.g., triple-glazed) windows can reduce the threat of fire-related losses.

- **Worker health and safety, and risk of lawsuits.** Various benefits result from improved indoor environmental quality, reduced likelihood of moisture damage, and other factors enhancing occupant health and safety (Chen and Vine 1998; Vine et al. 1998). Owners may face lawsuits when their buildings cause illness among occupants. According to a study by the American Medical Association and the U.S. Army, health problems caused by poor indoor air quality cost 150 million workdays and about $15 billion in lost productivity each year in the United States.[34] Increasingly, the issue of sick building syndrome ends up in the courts, with either builders/ designers or building owners being held liable for design flaws or improper operation. For example, in 1995 a jury awarded Polk County, Florida, almost $26 million to correct the contractor's health-related design and construction flaws in the County's eight-year-old courthouse. In 1996 a jury found Dupage County, Illinois, responsible – as the building owner – for health-related complaints at its $53 million courthouse, calling the problems a result of improper O&M.[34]

Risk (and associated losses) has a cost even when organizations are insured. Customer-side costs that occur when insurance is used include deductibles, premiums (and premium increases or policy cancellations due to losses), and possible excess costs if the insurance or reinsurance coverage is capped. If commercial insurance is not used (as is often, but not universally, the case in the government sector), the costs of risk are even higher because the facility owner is either formally or informally self-insured. Formal self-insurance implies that a predefined premium is set aside from internal budgets and accumulated in the form of an earmarked loss reserve. If self-insurance is informal (typically the case in the public sector), then the risks are not explicitly anticipated or otherwise reserved. Where formal or informal self-insurance is used in the public sector, risk management takes on particularly high value because there is no upper limit against loss costs and because losses would usually have to be absorbed in general operating budgets, without guaranty of reimbursement.

When Federal facilities do have insurance coverage, some insurance companies are willing to offer lower insurance premiums for buildings or sites that have incorporated features that not only improve safety but that also have positive environmental effects. For instance, insurance companies have lowered premiums for buildings with high mass walls because they reduce the risk of fire. These walls can also save energy and enhance comfort by storing heat and evening out temperature fluctuations. In another example of lower premiums, the Federal Emergency Management Agency reduced the premium on flood insurance by 5% for all buildings in unincorporated areas of Charleston County, South Carolina, based on voluntary efforts on the part of the developers of Dewees Island to improve the county's flood management capabilities by taking actions to reduce the chance of flooding on the island.[34]

A number of forward-looking insurers have endorsed or otherwise supported energy-efficient and renewable energy technologies by initiating various types of programs or policies (Mills 2003b). In some cases, insurance companies have offered premium credits of about 10% when the insured implemented selected energy-saving strategies. For example, the nation's largest professional liability insurer – DPIC – offers 10% credits for firms that practice commissioning, and the former

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[34] Rocky Mountain Institute website: http://www.rmi.org/sitepages/pid221.php.

Hanover Insurance Company offered 10% credits for earth-sheltered or solar buildings on the basis that lower fuel-based heating system operating hours reduce fire risk (Mills 2003b).

2.7.4 Greater Building Longevity

> *"If our buildings are not designed to last at least 250 to 300 years, we're not asking the right questions."*
>
> John Abrams, South Mountain Company (quoted in Building Green Inc. 2003)

Many of the principles of sustainable design lead to longer building lifetimes and better adaptability of the building for future uses that cannot always be foreseen. If buildings do not have to be frequently demolished and replaced, total construction costs will be lower over the long run. For instance, keeping a building's initial form simple will make it easier to change as needs evolve. Using open-web joists and modular access flooring systems makes refitting buildings for new uses less complicated. Designing rooms as multipurpose spaces allows them to be adapted for future changes in use (e.g., from residential to commercial space). Other strategies for adaptability include selecting durable materials that age well; designing roofs to be photovoltaic-ready; designing the building foundation and structure to accept additional floors at a later date; avoiding partitions and leaving as much open space as possible; and designing with classic and regionally appropriate styles.[35]

2.7.5 Better Resale Value

Although turnover of Federal government buildings is not as frequent as in the commercial real estate market, the Federal government does sometimes sell unneeded facilities. For instance, in 1998, the GSA sold over 1,500 properties for a total of about $250 million. In subsequent years, the GSA has sold between 130 and 300 buildings per year, for a total price per year of $312 million to $479 million.[36]

Research shows that investing in sustainable design features, such as energy- and water-efficiency measures, can considerably increase the resale value of a property because it lowers annual costs and therefore makes a building more profitable for the new owner (Chou and Parker 2000). Real estate investors evaluate building values based on cash flow and net operating income (NOI), which is the pretax operating income minus operating expenses, excluding debt service. Reducing utility costs increases NOI. A case study showed that a one-time investment in energy- and water-efficiency upgrades that cost \$0.95/ft^2 (1.8% of the purchase price) saved \$0.66/ft^2 in annual operating costs (equal to 15% of NOI) (Mills 2002). These savings increased the estimated resale value of the property (a small apartment building) by $36,000 to $46,000 (for prevailing capitalization rates of 9% and 7%, respectively) – about ten times the initial investment for the improvements.[37]

2.7.6 Ease of Siting

The inherent environmental benefits of a sustainable building will reduce its adverse environmental impacts and enhance its acceptability to regulatory bodies, the surrounding communities, environmental groups, and other interested parties. These benefits will tend to lower both the time delays and the cost associated with siting the building, including obtaining permits and performing

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[35] Many strategies for making buildings adaptable for new uses are outlined in a recent article in Building Green Inc. (2003).

[36] Personal communication from R. Rice, GSA.

[37] The capitalization or CAP rate (also knows as return on assets, ROA) is defined as the ratio of NOI to the property value. The ratio NOI/CAP provides an approximation of property value.

environmental impact studies. Gaining early respect and support from a community can greatly speed up project approvals. For example, the developers of Central Market, a grocery store in the town of Poulsbo, Washington, say that the decision to enhance an onsite wetland and offer it to the city as a park not only reduced maintenance costs but also avoided delays by generating strong community support. The developer, Sam Clarke, Executive Partner of the Hattaland Partnership, stated, "The city of Poulsbo and key community leaders are well aware of our work [to enhance the environment] —this establishes trust and respect, which translate eventually into financial advantages."[38]

2.7.7 Strategic and Economic Value of an Improved Image

An organization that owns and operates a sustainable building will tend to capture intangible value through stakeholder awareness and respect. While difficult to quantify precisely, this effect undoubtedly creates strategic advantage in dealing with various stakeholders, e.g., nongovernmental organizations, other agencies, and the public. In essence, the sustainable nature of the building can be considered a symbolic message to building visitors, as well as community members and passers-by who recognize its distinctive character. For example, innovative sustainable buildings in the private sector, including the headquarters buildings of The Gap and Herman Miller, as well as the Ford Motor Company Rouge Plant, have received extensive positive media coverage.

Key aspects of the message conveyed by a sustainable or green building include technological advancement, architectural innovation, and concern for humanity and the environment. The building owners can promote this message through various awareness-building techniques, including posters, brochures, organized tours, and media publicity. When the sustainability of the building reinforces the primary mission of a Federal agency (e.g., environmental management, energy efficiency, and technological innovation), this "image value" will be particularly powerful. Community groups, elected representatives, nongovernmental organizations, and others involved in the political process may view the Federal agency owner of a sustainable building as a supporter of their interests, and this positive view can translate into improved political support.

Some research has been conducted to evaluate indirect financial benefits of corporate sustainability efforts. While these efforts have not been directed specifically at sustainable building projects, they do have some relevance to understanding the value of the improved image associated with an organization's sustainability-related activities. For example, a number of "environmental accounting" techniques have been developed, using economic value added and other shareholder value measures, to estimate the likely future cash flows related to the environmental impacts of capital investments and facility siting decisions (Epstein and Young 1999).

One ongoing project by SustainAbility, a strategic management consultancy and think tank based in Europe, has established a mapping between business value measures and dimensions of corporate sustainable development performance, with documented examples that will be expanded through continued updating (SustainAbility and United Nations Environmental Program 2001). The SustainAbility project found strong evidence linking access to capital and shareholder value to a company's commitment to environmental process improvement. They also found strong evidence linking corporate revenue to good workplace conditions. These results indicate that both environmental and social aspects of sustainable design may impact a company's economic performance. Although the government is not motivated by revenue and shareholder value per se,

[38] Excerpted from Rocky Mountain Institute website: http://www.rmi.org/sitepages/pid221.php.

some government analogs to these metrics exist (e.g., revenue and access to capital in the private sector could be viewed as analogous to higher budget allocations in a government setting).

In another effort, the American Institute for Chemical Engineers (1999) developed a total cost assessment methodology for managerial decision-making that identifies the full range of environmental- and health-related costs associated with the lifecycle of a business decision, including indirect, contingent, and intangible costs. The World Resources Institute recently published a critical survey of the available methods for quantifying the business case for sustainability (Reed 2001). The greatest impediment to applying these types of quantitative methods is the absence of sufficient empirical data. Not enough experience exists yet with sustainable business decision-making to satisfy the needs of financial analysts. However, as this section has discussed in detail, research has been conducted on many important economic benefits of sustainable buildings, from which good inferences can be drawn about the strategic and financial advantages of sustainable design and construction.

2.8 Indirect Economic Benefits to Society

Building construction, operation, and demolition have a variety of environmental impacts, including air pollution emissions, greenhouse gas emissions associated with climate change, solid waste generation, water pollution, natural resource depletion, and habitat disturbance (see Section 4). Sustainable design aims to significantly reduce these impacts. These improvements will reduce the health effects and costs associated with environmental pollution and will have other less tangible economic value to society. In addition, by reducing energy consumption and waste generation, widespread application of sustainable design principles to new construction and renovations will, over time, reduce the need for new infrastructure required to support buildings – e.g., power plants, transmission and distribution lines, and landfills – and may foster local and regional growth in emerging businesses related to sustainable design. The economic aspects of these societal benefits – decreases in environmental pollution, reduced infrastructure needs, and local/regional business growth – are discussed in the sections below.

2.8.1 The Value to Society of Environmental Preservation and Pollution Reduction

Sustainable design strives to lower energy consumption and the resulting air pollution and greenhouse gas emissions, as well as to preserve natural resources, wildlife habitats (e.g., forests and wetlands), water bodies, scenic vistas, and other environmental assets. Economic values placed on such environmental "goods" are currently used for various purposes (mostly legal and policy issues), and natural resource economists have developed various means to estimate the value of natural resources and environmental impacts. Although some would say that something like a unique ecosystem is "priceless," certain groups within American society place economic value on, and are willing to pay for, environmental and natural resources. For instance, the Nature Conservancy is planning to invest $1 billion to save 200 of what they call the world's "Last Great Places."[39]

Various approaches have been applied to place a dollar value on reductions in air pollution emissions. One way is to examine the price firms pay to buy pollution "credits." The Clean Air Act established a program by which power plants were required to reduce their emissions of sulfur dioxide (SO_2) to a specific emission cap. The program allowed companies that could reduce emissions below their caps to sell the extra reductions ("credits") to other firms, allowing those other

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[39] http://nature.org/aboutus/campaign/.

firms to emit above their caps. As time progressed, firms with high costs of SO_2 control have chosen to buy credits from those with lower costs of control.

These emission credits are openly traded in the market. Recent prices have ranged from $90 to $272 per ton (National Research Council 2001). In addition, New Jersey and five other states in ozone nonattainment zones[40] have developed open market emission trading programs whereby building owners can generate emission credits by investing in energy efficiency, measuring the electricity saved and determining (based on a prescribed formula) the amount of air pollution emissions that were avoided by not generating the electricity. These credits have been sold for about $1000 per ton for nitrogen oxide (NO_x) (New York City Department of Design and Construction 2000). However, the current market value of air pollution credits does not necessarily reflect the full cost of pollution damages, e.g., negative health and welfare impacts.

A number of research studies, using a variety of methods,[41] have estimated the societal cost of a pollution. The cost ranges are wide because the methods and assumptions are diverse. The studies estimate the costs as follows (National Research Council 2001):

- Emissions of SO_2 at $100 to $7500 per metric ton ($91 to $6800 per ton)
- Emissions of NO_x at $2300 to $11,000 per metric ton ($2090 to $10,000 per ton)
- Emissions of carbon dioxide (CO_2) at $6 to $11 per metric ton ($5.50 to $10 per ton).

These values could be used, especially within a Federal government context, to estimate the societal benefit that reduced energy consumption in sustainable buildings has on reducing emissions.

In the prototype building analysis described in previous sections, the energy-efficiency measures led to the following emission reduction estimates: 0.16 tons of SO_2, 0.08 tons of NO_x, and 10.7 tons of CO_2.[42] Using the maximum values in the ranges above, these emission reductions might be valued as high as $1090 (for SO_2), $800 (for NO_x), and $107 (for CO_2), with a total annual cost reduction to society of $2000. This value ($2000) could be used to represent the annual benefit to society that would partially offset the incremental first cost of the energy-efficiency measures (which, in this case, was $38,000). Including these societal cost reductions in the payback calculation lowers the payback period from 8.7 to 6.0 years.

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[40] Nonattainment zones area areas with ambient concentrations of air pollutants that exceed the standards set to protect health and welfare.

[41] Some of these methods include indirect observed behaviors, direct hypothetical behavior, and indirect hypothetical behavior (for an overview, see descriptions by Randall [1987]; Freeman [1992]). The indirect observed behavior method tries to relate the value of a nonmarketed good (such as the price people would pay for a clean environment) to a marketed good (such as the price people would pay for recreational fishing). Economists commonly use the travel cost method or the hedonic/implicit price method. The travel cost method uses travel expenditure as the price paid to access a site, such as a natural park, to estimate a demand for that site. The hedonic/implicit price method investigates how a nonmarket good influences the value of a market good; hypothetically, this method could be used to estimate how a pristine environment surrounding a building might influence the rent or market price for that real estate. Direct and indirect hypothetical behavior uses hypothetical questions to elicit the value of a nonmarket good from a respondent (contingent valuation method).

[42] Expressed in tons of carbon in CO_2.

2.8.2 Reduction in Municipal Infrastructure Requirements

Taxpayers and local/regional governments benefit financially when they are required to invest in fewer new infrastructure projects. Some ways infrastructure needs are reduced through sustainable design include the following:

- Siting buildings near public transportation and including other features that encourage public and bicycle transportation rather than use of personal vehicles not only can reduce air pollution but also can reduce regional road and highway infrastructure requirements.
- Redeveloping brownfield sites or locating new buildings in downtown areas rather than suburban or rural greenfield sites reduces the associated development costs for new transmission/distribution systems, sewer systems, roads, and other infrastructure systems.
- Using recycled materials and construction waste management reduces demand for landfill capacity and therefore landfill construction costs.
- Reducing water use lowers the need for new wastewater/sewage treatment plants.

2.8.3 Local and Regional Economic Growth

Long-term socioeconomic benefits to a community and region may be realized if enough builders and building owners adopt sustainable design practices. For example, the sustainable buildings industry could foster a market for recycled materials and energy-efficient systems, creating sufficient economies of scale to reduce the price of these types of products to be more competitive with conventional products. In addition, surrounding communities and the region may experience economic development (including job creation) through emergence of businesses that make sustainable materials; produce energy-efficient technologies; and provide sustainable design, construction, and commissioning services. A region prone to practicing sustainable design and construction is an attractive place for these companies to locate. This potentially produces additional local jobs and income. Government sustainable design projects can be a "seed" for growth of sustainable communities and regions.

> *"Building on the many laudatory accomplishments of past generations, I want my generation, and my administration, to ensure that following generations can flourish and leave to their children a healthy and stable Oregon. We can and must reduce the pressures on our environment while increasing economic growth and community health."*
>
> Oregon Governor Ted Kulongoski, "Rally for the Environment Remarks," March 24, 2003. See http://www.oregonsolutions.net/oregon/index.cfm.

Sustainable building design also tends to favor local sources of materials and labor, further stimulating the economy adjacent to the building site and providing economic benefits that are particularly important in areas that are economically disadvantaged. For instance, the State of Oregon recently passed legislation, and the Governor signed an Executive Order, to promote sustainability in various government functions. One aspect of the initiative involves improving contracting practices to ensure that local contractors and businesses have competitive opportunities in rural and distressed communities.[43]

Another potential impact of sustainable design is an increase in property values adjacent to the sustainable building site. The characteristics cited above that contribute to quality of life will also tend to enhance the desirability of the neighborhood for developing other economic enterprises, including residential housing.

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[43] http://www.oregonsolutions.net/govt/group.cfm.

3.0 The Social Benefits of Sustainable Design

The social benefits of sustainable design are related to improvements in the quality of life, health, and well-being. These benefits can be realized at different levels – buildings, the community, and society in general. At a building level, research on the human benefits of sustainable design has centered on three primary topics: health, comfort, and satisfaction. Although these outcomes are clearly interrelated, they have different scholarly roots and employ different methodologies. Health issues are the domain of epidemiologists and public health professionals. Comfort is studied by researchers with expertise in building science and physiology, while well-being and psychosocial processes are studied by environmental and experimental psychologists. The research described in this section integrates findings from these diverse areas, with a focus on studies that assess the health, comfort, and well being outcomes associated with the presence or absence of sustainable building components.

The building environment can have both negative and positive impacts on the occupants' quality of life. Negative impacts include illness, absenteeism, fatigue, discomfort, stress, and distractions resulting from poor indoor air quality, thermal conditioning, lighting, and specific aspects of interior space design (e.g., materials selections, furnishings, and personnel densities). Reducing these problems through sustainable design often improves health and performance. Improved indoor air quality and increased personal control of temperatures and ventilation have strong positive effects. In addition to reducing risks and discomforts, buildings should also contain features and attributes that create positive psychological and social experiences. Although less research has been done on health-promoting environments, emerging evidence shows that certain sustainable building features, including increased personal control over indoor environmental conditions, access to daylight and views, and connection to nature, are likely to generate positive states of well- being and health.

Another emerging social issue affecting buildings is security. Since September 11, 2001, Federal agencies have experienced heightened concern about how a building's features affect its ability to thwart or withstand hostile actions. The relationships between sustainable design and building security are important topics that will be discussed in this section.

At a community or societal level, the social benefits of sustainable design include knowledge transfer, improved environmental quality, neighborhood restoration, and reduced health risks from pollutants associated with building energy use. Although more research has been conducted on the benefits of sustainable design features to building occupants, interest is growing in the community benefits of sustainable design, and several potential areas of value to the Federal government are discussed at the end of this section.

The first two sections below describe research results indicating positive impacts of sustainable buildings on occupant health (Section 3.1) and comfort, satisfaction, and well-being (Section 3.2). (Appendix F discusses these topics in more detail.) Section 3.3 describes the potential benefits of energy efficiency and other sustainable design features to occupant safety and security. Section 3.4 describes potential positive community impacts.

3.1 Better Health of Building Occupants

Studies of the health benefits of sustainable design focus primarily on indoor environmental quality, especially air quality. Health effects result from environmental stimuli interacting with the body's physical systems, especially respiratory, skin, neural, and visual pathways. Illness symptoms occur because environmental agents (such as chemicals or airborne microbials) affect the operation of the body's physical systems in vulnerable persons.

Many studies have found high levels of air-quality problems and occupant illnesses in office buildings (e.g., Brightman and Moss 2001). Studies have begun to assess the causal relationships between the building environment and illness symptoms in three areas: (1) sick building syndrome (SBS), (2) asthma and allergies, and (3) communicable and respiratory diseases (Fisk 2001). Research Summary 3-1 shows an example of such a study. The findings of this research show that the three types of illnesses are affected by different components of the environment:

- **Sick building syndrome.** SBS symptoms include headache; fatigue; dizziness; irritations of the skin, eyes, and nose; and difficulty breathing. A large review study of the links between health, perceived air quality, absenteeism, and ventilation found that ventilation rates lower than 10 L/s per person were associated with statistically significant worsening of symptoms in a range of building types.[44] Increases in ventilation rate above 10 L/s up to 20 L/s per person were associated with decreased symptoms and improvements in perceived air quality. A ventilation increase of 5 L/s per person could reduce the proportion of workers with these respiratory symptoms from 26% to 16% and those with eye irritations from 22% to 14% (Seppanen et al. 1999). SBS symptoms are also reduced by personal control over thermal conditions (Preller et al. 1990; Hedge et al. 1993), improvements in ventilation system maintenance and cleaning, reduced use of pesticides, and daily vacuuming (Sieber et al. 1996).
- **Allergy and asthma symptoms.** Several building factors – moisture problems, molds, and dust mites – are strongly associated with asthma and allergy symptoms (Fisk 2002). Reducing the concentrations of allergens and irritants reduces symptoms. Successful strategies for reducing such concentrations include improving HVAC maintenance and cleaning and using building practices that reduce moisture buildup (Sieber et al. 1996). Other strategies include air filtration, humidity control, and elimination of indoor smoking. Asthma symptoms were found to more likely occur in the presence of new drywall and in building interiors with cloth partitions (Sieber et al. 1996).
- **Transmission of infectious diseases.** Infectious diseases can be transmitted by airborne microbes (viruses, bacteria). Airborne transmissions can be reduced significantly through ultraviolet irradiation of air near the ceiling, improved ventilation, and reduced crowding (Fisk 2000b; Seppanen et al. 1999). One study found that workers with one or more officemates were 20% more likely to have two colds during the year than workers who did not share an office (Jakkola and Heinonen 1993). Studies showing reduced risk with lower crowding do not identify what level of density is desirable for health reasons.

Health problems can be linked to absenteeism. A study of absenteeism among office workers in a large East Coast company found that the absenteeism rate was 35% lower in offices with higher

[44] Ventilation and air circulation are important, but sometimes overlooked, features of sustainable buildings. Ventilation refers to the air exchange between the outside and the inside of the building. Circulation refers to the air movement within and between the interior spaces of the building. Both ventilation and circulation can be achieved through mechanical means (e.g., fans within air ducts) or by utilizing natural principles (e.g., warm air naturally rises). In either case, a well-designed system should provide sufficient ventilation to dilute contaminants generated within the building space (by either building components or occupants) as well as adequate air circulation within and between building spaces to disperse built-up air contaminants locally while not adversely affecting the occupants' perception of temperature (e.g., creating drafts). It is particularly important that measures to increase energy efficiency by "tightening up" a building take into consideration the need to maintain adequate ventilation rates. Good ventilation and energy efficiency can be achieved simultaneously by using sustainable building measures such as heat recovery devices.

ventilation rates (about 24 L/s per person) compared with moderate rates of 12 L/s ((Milton et al. 2000). The use of humidification and complaints about air quality were also associated with increased sick leave. The study analyzed sick leave of 3720 hourly workers in 40 buildings. The study controlled for gender, age, seniority, hours of nonillness absence, shift, ethnicity, crowding, and type of job. (See Section 2.6 for additional information about absenteeism.)

Research Summary 3-1: Improved Ventilation Rates and Lower CO_2 Concentrations Reduce Illness Symptoms in Office Workers

Researchers conducted a critical review and synthesis of research on the associations between ventilation rates and occupant health to provide a scientific basis for setting health-related ventilation standards. The review shows that illness symptoms are often associated with low ventilation rates, high CO_2 concentrations, and perceptions of poor air quality.

Research Team: The research team included O.A. Seppanen from Helsinki University of Technology, W.J. Fisk from Lawrence Berkeley National Laboratory, and M.J. Mendell from the National Institute for Occupational Safety and Health.

Methodology: Both cross-sectional and experimental studies were reviewed. The following criteria were used for including cross-sectional studies:

- The study included at least three buildings or ventilation zones.
- Results were statistically analyzed and included controls for other factors that can influence health outcomes.

The following criteria were used for including experimental studies:

- No changes occurred in the air-handling system, and occupants did not move to a different building.
- A control group or multiple applications of experimental conditions were used.
- The subjects were not aware of the timing of changes in the ventilation rates.
- Results were statistically analyzed.

These criteria resulted in the selection of 20 studies with 30,000 subjects for investigating the association between ventilation rates and human responses, and 21 studies with over 30,000 subjects for investigating the relationship between CO_2 concentrations and human responses.

Key Findings: Some of the key results of the review are as follows:

- All studies assessing respiratory illness found a significant increase in the risk of illness with lower ventilation rates.
- Of the 27 studies dealing with SBS, 20 found a significantly higher prevalence of at least one symptom with lower ventilation rates.
- Findings of illness symptoms were especially consistent with ventilation rates of less than 10 L/s per person.
- Lower ventilation is also associated with increased perceptions of poor air quality.
- CO_2 studies supported the ventilation findings; in half of the studies, symptoms improved significantly when CO_2 concentrations were below 800 parts per million (ppm).
- Studies did not find a definitive ventilation rate that prevented symptoms.
- Only 5 of the studies were conducted in hot humid climates. Results may therefore apply primarily to moderate and cool climates.

Source: Seppanen et al. (1999).

3.2 Improved Comfort, Satisfaction, and Well-Being of Building Occupants

Psychological effects (e.g., comfort, satisfaction and well-being) are generated through perceptual and sensory processes that interpret environmental information in terms of its effect on current needs, activities, and preferences. The psychological "interpretation" of the environment has consequences for work performance and productivity (as discussed in Section 2.6), stress, and well-being. Because of the inherent variability in psychological responses, the same environmental conditions can affect different people in different ways as well as affect the same person differently over time, depending on the context.

Occupant comfort and satisfaction with building conditions are a primary focus of post-occupancy evaluations. The research generally shows that occupants' satisfaction with lighting and air quality is higher than their thermal and acoustic satisfaction (Leaman and Bordass 2001). Efforts to improve comfort and satisfaction are important because discomfort has negative consequences for work effectiveness, job satisfaction, and quality of work life.

A number of studies indicate that certain building features such as daylight, views, connection to nature, and spaces for social interaction, appear to have positive psychological and social benefits. The benefits include reduced stress, improved emotional functioning, increased communication, and an improved sense of belonging.

Occupants' satisfaction with several building features has been examined in a number of studies described below:

- **Satisfaction with daylighting and electric lighting.** A study of seven energy-efficient buildings in the Pacific Northwest found that 70% of the occupants were satisfied with lighting overall (Heerwagen et al. 1991). Factors that most influenced lighting satisfaction were access to windows and daylight, some degree of control over lighting, and the occupant's location in the building (those on the east and in corner spaces were most satisfied). Workers in windowed areas were 25% to 30% more satisfied with lighting and with the indoor environment overall, compared with workers having reduced access to windows. The Pacific Northwest study found that occupants valued daylight for its variability both across the day and across seasons (Heerwagen et al. 1991). Several reviews have also found that satisfaction with electric lighting improves with reduced glare problems and with increased brightness of vertical surfaces, including walls and cubicle partitions (Collins et al. 1990; Collins 1993).

- **Thermal satisfaction.** Thermal satisfaction is consistently lower than lighting satisfaction in most building studies partly because of the high variability in thermal comfort. Occupant responses to the thermal environment are influenced by activity, clothing levels, stress, age, gender, and individual preferences. The most effective way to improve thermal comfort and satisfaction is by using individual controls for temperature and ventilation (Wyon 1996). The responsiveness of building management to complaints also improves comfort and satisfaction (Leaman and Bordass 2001).

- **Perceptions of air quality.** Negative perceptions of air quality are common and are associated with low ventilation rates (Seppanen et al. 1999). In six cited studies, 50% of occupants said the air quality in their buildings was unacceptable, even though the building itself was not considered a "complaint" building (Seppanen et al. 1999). Increased ventilation improves perceptions of air quality if the intake air itself is located at least 25 feet from an irritant source (e.g., an exhaust vent, traffic, or a trash dumpster) (Sieber et al. 1996). Air quality is also associated with food and its odor problems, especially when the food is eaten by workers at their desks (Heerwagen et al. 1991).

- **Overall satisfaction.** A recent, large-scale study (Leeman and Bordass 2001) of 16 buildings in England identified several features that were consistently associated with higher levels of overall satisfaction:
  - Shallower plan forms and depths of space (buildings and rooms that are long and narrow)
  - Thermal mass
  - Stable and comfortable temperature conditions
  - Operable windows
  - Views out
  - Usable controls and interfaces
  - Places to go at break time
  - A well-informed and responsive building management.

- **Psychosocial well-being.** Although sunlight can create glare and heat gain in buildings if it is not controlled properly, evidence suggests that a modest level of sunlight indoors ("sun spots") significantly enhances psychological functioning and job satisfaction compared with spaces lacking daylight and sun (Leather et al. 1998). Although people prefer being in windowed rather than windowless spaces, the view itself has consequences for well-being. Studies have found that views of nature are especially beneficial and reduce stress, provide mental relief, improve perceived quality of life, and improve emotional functioning (Ulrich 1984; Clearwater and Coss 1990). A case study (Heerwagen 2000) of the Herman Miller building in Holland, Michigan, shows improvements in social functioning and sense of belonging associated with including break areas; a centrally located cafeteria; an interior, daylit and tree-lined "street"; and high levels of internal glazing that offered views into the street and interior spaces (see Research Summary 3-2).

3.3 Occupant Safety and Security

In the wake of the September 2001 attacks, every Federal agency faces a heightened concern for providing safe and secure workplaces and public spaces in Federal office buildings, military facilities, and other public facilities. At first, it might seem that features aimed at improving security will inevitably require some sacrifice of energy efficiency or other sustainable design characteristics. For example, sustainability principles might be considered inconsistent with using additional steel and concrete to increase blast resistance, eliminating natural ventilation, reducing window areas (daylight, passive solar heating) to minimize danger from flying glass, and increasing energy use from ventilation fans associated with high-performance air filters.

> *"In the process of renovating the Pentagon, we've found that several of the force protection measures we are taking to protect the Pentagon against terrorist attacks are complementary to our sustainable construction efforts. These are all examples of building security and energy efficiency working hand in hand."*
>
> Teresa Pohlman, Special Assistant for Sustainable Construction, U.S. Department of Defense

While such tradeoffs may be required in specific cases, a careful examination of the options for integrated design, at both the individual building level and at the site (or "campus") as a whole, has led many designers to conclude that improved building security and improved energy efficiency/sustainability not only can coexist but can even be complementary.

Research Summary 3-2: Herman Miller Improves Worker Satisfaction and Productivity

This study examined occupant satisfaction, as well as productivity (based on Herman Miller's own TQM metrics). Results indicate that the new sustainable building had positive impacts on occupants' well-being, job satisfaction, feelings of belonging, and other aspects of work life that affect individual job performance. The study also found that a small increase in organizational productivity occurred after the move to the new building.

Research Team: PNNL, J. Heerwagen, lead.

Research Setting: The Green House, designed by William McDonough and Partners of Charlottesville, Virginia, is a 290,000-ft^2 building that combines a manufacturing plant and office facilities/showroom for Herman Miller, Inc., a furniture manufacturing company. This facility is located in Holland, Michigan. The building has the following sustainable features:

- Extensive daylighting, including an interior daylit "street," windows, skylights, and roof monitors in the manufacturing plant
- Operable windows in both the manufacturing plant and office
- Views to the surrounding countryside from all locations
- Energy-efficient glazing and lighting
- Lighting controls that dim electric lighting when daylight is sufficient
- Occupancy sensors
- Increased filtration of particulates and increased air changes/hour in the manufacturing plant
- Nontoxic adhesives and a separately ventilated painting area in the manufacturing plant
- Restored prairie landscape and wetland on the site
- Extensive recycling of waste from the cafeteria, office, and manufacturing plant
- Siting to reduce the visual impact of the building from the road
- In-house fitness center.

Methodology: A research team from PNNL conducted a pre- and post-occupancy study that included occupant surveys and analysis of organizational TQM data. The data included overall productivity, on-time delivery, product quality, and efficient use of materials. DOE's Office of Building, Technology, State and Community Programs funded the study.

Key Findings: After moving into the new facility, the occupants experienced the following:

- Increased sense of well-being, belonging, and work spirit
- Increased job satisfaction
- Increased feeling of looking forward to work and being in good spirits at work
- Higher satisfaction overall with the building, especially the daylight, windows, electric lighting, air quality, and connection to nature.

The responses of the manufacturing workers varied across the shifts, with the daytime workers responding most positively. The night workers showed little difference between the buildings, possibly because the environment changed the least for them (daylight, views, and connection to the outdoors are greatly diminished at night).

Analysis of the pre- and post-occupancy results related to Herman Miller's TQM led to the following conclusions:

- A small increase of 0.22% occurred in overall productivity and small increases of 1% to 2% occurred in other TQM metrics. These increases were small but are still significant because the organization was already performing at 98% to 99% on all of the TQM metrics.
- No dip in productivity occurred following the move to the new facility. Most moves or major changes are followed by a period of slowdown, but this did not occur.
- No differences occurred in any of the TQM metrics across the manufacturing shifts, despite the differences in perceptions and subjective outcomes. This result suggests that the link between performance and subjective experiences is more complicated than is currently believed.

Source: Heerwagen (2000).

Examples of the synergy between building security and sustainability features can be seen from the Pentagon renovation project.[45] A spray-on wall coating selected to improve blast-resistance also helps improve the air tightness of the building envelope. The tighter envelope not only saves heating and cooling energy but also provides added protection against outside releases of airborne chemical or biological agents. The U.S. Department of Defense reports that new blast-resistant windows chosen to replace the original ones at the Pentagon are also 50% more energy efficient. Another feature is the choice of photo-luminescent signage to mark evacuation routes; these require no standby power and are also easier to see through smoke caused by a fire or explosion than conventional exit signs. A final example from the Pentagon project is the use of zoned climate control systems that not only reduce heating and cooling energy use and improve indoor air quality but also make it easier to control smoke and manage the spread of chemical or biological toxins in response to an emergency.

The U.S. Department of State is actively researching innovative structural and glazing systems that provide both daylight/view and – because they are designed to yield to an external blast – better protection for building occupants. Planners responsible for overseas Embassy compounds also maintain that the greater setbacks required for new buildings also provide important opportunities for sustainable landscaping, solar access, and other highly desirable features as a valuable by-product of security requirements.

The National Aeronautics and Space Administration incorporated both building security guidelines and sustainable design in their criteria for new facilities. They have found that certain standard design criteria, such as structural requirements for wind and seismic loads, can also help improve blast-resistance.

Ideally, projects targeted at improving building security should also consider opportunities to "piggyback" energy-efficiency and renewable energy measures because the energy cost savings could make security improvements more affordable. A few other examples of positive interactions between security and efficiency measures in buildings include the following (Harris et al. 2002):

[45] Personal communication with T. Pohlman, U.S. Department of Defense, Washington, D.C.

- Improving control of air distribution systems – including periodic calibration of sensors, adjustment of dampers, and other system maintenance – is essential for rapid response to an emergency and also contributes to energy-efficient operation under normal conditions.
- Tighter building envelopes have the dual benefits of reducing energy losses from air infiltration and making it easier to pressurize a building and therefore reducing entry of airborne hazards released outside the building.
- Daylit spaces may be easier to evacuate quickly in the event of an attack or threat accompanied by a power outage.
- Onsite power systems can be very attractive considering their improved reliability during utility system outages (either natural or human-caused), in addition to any cost savings that might be associated with reduced electricity or peak power demand.
- Upgrading existing windows for blast resistance may create opportunities to improve thermal and optical (daylighting) performance, if the window system or add-on film is selected carefully. For example, in planning for a recent retrofit project, DOE evaluated several blast-resistant films with varying thermal and optical properties and then pilot-tested the samples on windows in several offices.
- Redesigning security lighting along with automated sensing and surveillance systems may actually reduce the need for constant high nighttime lighting levels, while improving detection capabilities.
- Improving particle air filtration has several potential benefits. In addition to protecting buildings from biological agent attack, the benefits include reducing indoor particle concentrations from other sources, thereby improving occupant health (and productivity), and helping reduce HVAC coil fouling, which in turn improves heat exchange efficiency. Some high-performance filters have significantly lower pressure drop than others that do the same job, so a careful choice of filter systems and products can produce cleaner and safer air with less energy penalty.
- Site planning that provides a wide buffer zone to keep vehicles away from the exterior of a public building can also provide opportunities for better solar access and for climate-appropriate landscaping. Trees can directly shade the building and both channel prevailing summer breezes toward the building and temper the effect of cold winter winds on space heating loads. In addition, trees and other vegetation cool the building site due to evaporation that occurs during the plants' normal biological processes (evaporation causes cooling).

More examples can be found in Research Summary 3-3 at the end of Section 3.

3.4 Community and Societal Benefits

The effects of sustainable building practices on occupants are the primary social benefits that have been researched; however, various secondary and indirect quality-of-life benefits, for which anecdotal evidence exists, can accrue to other societal groups.

From a public health perspective, quality of life can be measured in terms of individual life expectancy and state of wellness. More generally, quality of life at a community level can include such issues as environmental quality, aesthetics, educational and recreational opportunities, accessibility and quality of public services, and even psychological characteristics such as community satisfaction and pride.

Sustainable building practices can contribute to quality of life in a number of ways:

- Occupants who experience increased job satisfaction, health, and productivity will carry these experiences back to their families and friends in the community, thus influencing overall well-being.
- Occupants may also enjoy more pleasant and productive commutes to work and less traffic congestion in their communities if public or alternative transportation methods are made available at their workplace.
- Benefits can potentially diffuse beyond the workplace and lead to increased use of sustainable design practices and behavioral change in the community at large. Behavioral changes might include increased recycling, purchasing green products, and investing in energy-efficient technologies.
- Buildings that include sustainable features also become models for others to follow. For example, the Herman Miller Green House regularly provides tours and outreach programs for local and national design and construction professionals as well as for businesses that are planning their own sustainable buildings.
- Environmentally conscious construction practices will tend to generate lower amounts of dust, pollution, noise, traffic congestion, and other community disturbances. These improvements will likely contribute to improved public health, safety, and well-being. (The environmental benefits of sustainable buildings are discussed in greater detail in Section 4.)
- Construction practices and building operation practices that foster recycling and reduce waste generation, energy use, and water consumption will eventually reduce the demand for new landfills, electric utility plants, transmission and gas pipelines, and wastewater treatment facilities (see Section 2.7), and will decrease the public nuisance associated with them.
- Use of locally produced and manufactured products in sustainable buildings bolsters the local economy and provides jobs in the community (as well as reducing energy use and emissions caused by long-range transportation of goods).
- If sustainable design involves cleanup and use of a brownfield site, the community may benefit from the improved environmental conditions associated with the cleanup. It may also experience economic development associated with productive use of a previously unused site and the presence of a new set of workers who make financial transactions in the community. (The socioeconomic effects of sustainable buildings on community development, improved health due to lower pollution loads, and reduced infrastructure needs were discussed in Section 2.7.)

Research Summary 3-3: Energy-Efficiency Upgrades Offer Opportunities for Improved Building Security

The following table is the result of a recent effort by Lawrence Berkeley National Laboratory to assess the security implications of energy-efficiency measures (Harris et al. 2002).

			Security Issue*
Project Planning and Management			
Integrated design process*	Design objectives	Clearly define goals and minimum requirements for sustainability/efficiency and security as part of an organization's architectural programming	Con, Air, Ex, RR
	Architectural and engineering solicitation and contracting	Specify required expertise in sustainability and security when issuing the solicitation and use explicit criteria for selecting an architectural and engineering firm; include integrated design tasks in the contract	
	Design charrette	Allocate time and resources for integrated design charrette(s) at an early stage of design, including a broad range of participants	
Architectural Considerations			
Building envelope	Airtight barrier	Appropriately seal buildings to both resist chemical/ biological penetration and provide weather-tightness	Air
	Insulation	Insulate walls to provide a secondary barrier and thermal savings	Air, Ex
	Impact-absorbing walls	Use innovative walls systems (multiple layers, openings, crumple zones) designed to absorb blast effects that can also reduce envelope heat transfer and control solar gain	Ex
	Thermal mass	Design earth berms for blast deflection, which can also provide thermal buffering	Ex
		Specify high-mass (concrete) construction, which allows active or passive use of thermal mass to reduce heating/cooling loads	Ex
	Shading devices	Design shading devices that can double as blast protection	Ex
	Vestibules	Use vestibules to help control building access while reducing infiltration of unconditioned outside air	Con, Air
Windows	Laminate films	Apply blast-damage-resistant laminate films to interior surface of windows with appropriate emissivity and visible light transmittance	Air
	Operable windows	Analyze appropriate response to threat (http://securebuildings.lbl.gov/)	Air, RR
	Protective screens	Use external protective screens that may also control unwanted solar gain	Ex
	Storm windows	Consider retrofitting storm windows with efficient (low-e, solar control) films	Air, Ex

			Security Issue*
HVAC Considerations			
Air systems	System design	Consider separating ventilation air systems from thermal distribution. Radiant cooling/heating with hydronic distribution offers added efficiency; smaller, ventilation-only fresh-air supply and dedicated exhaust systems are easier to control in an emergency.	Air, RR
		Provide larger ducts and efficient fans for rapid venting and energy savings in normal operation	Air, RR
		Use efficient ventilation systems (displacement ventilation, large ducts, etc.) to reduce space and energy requirements for upgraded filters	Air, RR
	Variable-speed drives	Provide capability for normal operation and rapid venting (variable-speed drives also allow for dynamic braking to stop fans faster in an emergency)	Air, RR
	Dedicated exhaust	Provide separate additional exhaust for emergency venting or for economizer operation, especially in high-risk areas such as entry vestibules, loading docks, and mail rooms	Air, RR
	Whole-building ventilation	Consider dual use of building purging systems (for smoke and also chemical contaminants) to provide nighttime “free cooling” during normal building operation	Air, RR
	Duct leakage	Specify, install, and commission (test) ductwork for low leakage	Air, RR
	Dampers	Provide dampers with rapid closure and low leakage	Air, RR
	Filtration	Use low-pressure drop filters at the filtration level needed	Air, RR
		Tightly seal around in-line filters	Air, RR
	Security barriers	Review impact of security barriers, such as additional doors, on normal air distribution	Con, Air
Water systems	Physical layout	Provide secure enclosures and minimize run lengths of piping	Air, Ex
		Increase pipe size	Ex
Control System Considerations			
Window controls	Operable window controls	Provide automatic and operator control for chemical/biological isolation and thermal comfort	Air, RR
	Shading control	Provide automatic and operator control for blast protection and shading	Ex, RR
Integrated controls	Interoperable systems	Use interoperable systems to integrate security controls with other building controls (HVAC, lighting, access, surveillance, fire/smoke)	Con, Air, Ex, RR
		Plan for future additions as new sensing capability is developed	Con, Air, Ex, RR

			Security Issue*
Control System Considerations (contd)			
HVAC controls	Individual control of fans, dampers	Provide for pressurized safety zones when needed	Air, RR
	Alternate filtration path	Provide parallel path through filter banks during chemical/biological attack	Air, RR
Wireless systems	Remote monitoring and control	Provide secure and redundant controls using wireless and web-based systems	Con, Air, Ex, RR
Monitoring	System status monitoring	Provide whole-building system monitoring to improve maintenance, normal operation, and critical monitoring during events	Con, Air, Ex, RR
Elevator controls	Integrate elevator controls with building control systems	Integrate elevator controls for emergency response to fire or chemical/biological events and for efficient operation. Make elevators controllable to allow implementation of peak-load strategies.	Con, Air, Ex, RR
Lighting Considerations			
Interior/ exterior lighting	Security lighting	Provide efficient lighting and lighting controls such as motion sensors	Con
		Integrate lighting into overall building controls	Con, RR
Interior	Daylight access	Minimize interior spaces without daylight access to improve visibility in daytime emergency evacuations	RR
Distributed Generation			
Backup generation	Combined heat and power; renewable fuels	To reduce power and fuel costs during non-emergency periods, upgrade emergency backup generation from diesel to renewable onsite power (photovoltaics, wind, biofuels) or a gas turbine, combined with heat recovery for space heat or hot water	RR
Site Planning			
Building site	Site design and landscaping to reduce heating and cooling loads	Add protective open space around structures to allow buildings to be oriented for passive solar features	Con, Ex
		Use larger setbacks to allow trees and plantings to directly shade buildings and buffer or channel prevailing winds, to provide evapotranspiration cooling, and to reduce urban heat-island effects	
	Physical barriers	Add berms and water features to provide blast protection and access control, as well as stormwater/erosion management	
Campus layout	Sustainable site planning and management	Plan for larger, multi-use sites to enhance security, create opportunities for efficient water use/recovery/ recharge and ground-source heat pumps, and allow better load matching for onsite combined heat and power, etc.	Con, Ex

			Security Issue*
Other			
Cyber – security	Computer standby power	Physically shut off power to computers at night and during unoccupied periods to save energy while reducing risk of unauthorized access to data and systems.	Con
* Con = control of access; air = airborne (chem/bio) threat; Ex = explosive threat; RR = response and recovery. ** For more details, examples, and useful links, see www.wbdg.org/design.			

4.0 The Environmental Benefits of Sustainable Design

Buildings consume a significant amount of our natural resources and have a wide range of environmental impacts. These environmental concerns are a key driver behind the sustainable design movement. Various estimates indicate that buildings use 30% of the raw materials consumed in the United States (EPA 2001). Considering what buildings are made of – steel, concrete, glass, and other energy-intensive materials – buildings have a high level of "embodied" energy. Based on lifecycle assessments, the structural and envelope material of a typical North American office building has 2 to 4 gigajoules per square meter (175 to 350 kBtu/ft^2) of embodied energy (Building Green Inc. 2003). Producing these materials depletes nonrenewable resources and has environmental effects, and these impacts intensify the more frequently buildings are demolished and replaced.

> *"Typically, embodied energy [in a building] is equivalent to five to ten years of operational energy."*
>
> William Bordass, quoted in Building Green Inc. (2003)

Building operations also contribute significantly to environmental pollutant levels in the United States and abroad. As a whole, U.S. buildings use 36% of U.S. energy demand, 68% of the country's electricity (more than half of which is generated from coal), and nearly 40% of U.S. natural gas consumption (DOE 2002). As a result, U.S. buildings are accountable for 48% of the nation's SO_2 emissions, 20% of the NO_x, and 36% of the CO_2 (DOE 2002). Buildings also produce 25% of the solid waste, use 24% of the water, create 20% of the water effluents, and occupy 15% of the land (EPA 2001). In addition, U.S. builders produce between 30 and 35 million tons of construction, renovation, and demolition waste (DOE 2002).

Federal facilities contribute a notable portion of these building impacts; for example, Federal buildings are estimated to emit 10.5 million metric tons of CO_2 (in carbon equivalents) (DOE 2001), which is about 2% of the total emissions from U.S. buildings and is equivalent to the total emissions of Peru.[46]

From a complete lifecycle assessment perspective, construction, operation, and demolition or reuse of buildings involve a chain of economic activities that provide the goods and services necessary to build, maintain, and eventually retire or convert the asset. Each of these activities carries an implicit "ecological footprint" of resource consumption and waste generation. For example, the footprint associated with a ton of steel includes impacts of mining, transportation, and manufacturing operations, including a considerable amount of energy consumed in converting iron ore to steel and transporting the steel to its point of use. Table 4-1 lists the sources of pollution and other negative environmental impacts related to constructing, operating, and demolishing buildings.

Applying sustainable design principles can significantly reduce these impacts. The following sections describe three categories of environmental benefits attributable to sustainable buildings: lower air pollutant and greenhouse gas emissions to the atmosphere (Section 4.1), reduced volumes of waste (Section 4.2), and decreased use of natural resources and lower impacts on ecosystems (Section 4.3). Each section is illustrated with a case study.

[46] http://cdiac.esd.ornl.gov/trends/emis/per.htm.

Table 4-1. Examples of Environmental Impacts of Buildings

Construction	Operation	Demolition
Materials Use • Depletion of nonrenewable resources • Pollution and byproducts from materials manufacture • Construction materials' packaging waste **Site Preparation and Use** • Disturbance of animal habitats • Destruction of natural vistas • Construction-related runoff • Soil erosion • Destruction of trees that absorb CO_2 • Introduction of invasive exotic plants • Urban sprawl (for greenfield sites) and associated vehicle-related environmental impacts (e.g., tailpipe emissions as well as impacts of highway, road, and parking lot construction) • Water quality degradation from using pesticides, fertilizers, and other chemicals	**Energy Use** • Air pollution: emissions of SO_2, NO_x, mercury, and other heavy metals and particulate matter from power plants; the building's energy consumption; and transportation to the building • Greenhouse gas (CO_2 and methane) emissions, which contribute to global warming • Water pollution from coal mining and other fossil fuel extraction activities, and thermal pollution from power plants • Nuclear waste, fly ash, and flue gas desulfurization sludge from power plants that produce the electricity used in buildings • Habitat destruction from fuel extraction **Building Operations** • Runoff and other discharges to water bodies and groundwater • Groundwater depletion • Changes in microclimate around buildings and urban heat island effects • Ozone-depleting substances from air conditioning and refrigeration • Light pollution in the night sky • Water consumption • Production of wastewater that requires treatment • Production of solid waste (garbage) for disposal • Degradation of indoor air quality and water quality from using cleaning chemicals	• Demolition waste (used steel, concrete, wood, glass, metals, etc.) • Energy consumption for demolition • Dust emissions • Disturbance of neighboring properties • Fuel use and air pollutant emissions associated with transporting demolition waste

4.1 Lower Air Pollutant and Greenhouse Gas Emissions

One set of environmental benefits from greening buildings that can be fairly easily estimated is lower air pollutant and CO_2 emissions. Emissions are reduced by decreasing energy use through energy-efficient design, use of renewable energy, and building commissioning. Table 4-2 shows the average amounts of emissions that are released per Btu of natural gas and electricity used (these are called "emission coefficients"). The coefficients also indicate the amount of pollution that would be reduced per unit of energy saved.

Table 4-2. Emission Coefficients for Energy Consumption in Commercial Buildings

	SO_2 Million Short Tons	NO_x Million Short Tons	CO_2 Million Short Tons Per Quad
Natural gas	Negligible	0.08	15.8
Electricity (per delivered quad)	0.97	0.45	55.62
Source: DOE (2002). (1 short ton equals about 0.91 metric ton.)			

In the hypothetical prototype building, annual emissions would be reduced by 0.16 short tons of SO_2, 0.08 tons of NO_x and 10.7 short tons of CO_2[47] (based on site electricity reduction of 167 million Btu and a natural gas savings of 86 million Btu). This reduction is small compared with national emission levels[48] or even emission levels in a city such as Baltimore. However, given that buildings contribute 48% of SO_2, 20% of NO_x, and 36% of CO_2 nationwide (DOE 2002), a widespread adoption of sustainable design techniques in new and retrofit buildings would eventually affect national and regional pollution levels.

Reducing SO_2 and NO_x is particularly important in areas (such as Baltimore) that are not achieving air quality standards. Large urban areas with intense traffic and areas affected by emissions from large industrial sources and power plants can have ambient air pollution levels that exceed the amounts determined by the EPA to protect human health and welfare ("National Primary and Secondary Ambient Air Quality Standards," 40 CFR 50). Although buildings are not typically a target of specific emission regulations, some states such as New York encourage emission reductions from nonregulated sources through a program of "emission reduction credits." Through this program, a regulated source can pay a nonregulated source for emission credits earned by reducing emissions through energy-efficiency measures, fuel switching, or other means.[49] When aggregated, the lower emissions from small sources of NO_x (such as gas-fired heating systems in buildings) in cities can help reduce ozone-related pollution (smog). In addition, cutting electricity consumption helps decrease emissions of NO_x and SO_2 from power plants (usually located in rural areas), thereby helping to reduce regional environmental problems, such as acid rain.

Reducing fuel and electricity consumption also lowers CO_2 emissions, a greenhouse gas that is linked to climate change. Decreased use of natural gas should also reduce methane emissions to the atmosphere (methane is another greenhouse gas). The effects of the buildup of greenhouse gases in the atmosphere may include sea level rise, weather changes (e.g., increase in violent weather patterns), and impacts on agriculture. Although climate change is likely to occur gradually over a long time period, energy-efficiency measures implemented now will slow the pace of the greenhouse gas buildup and its potential effects.

Case Study 4-1 describes how a photovoltaic energy system has lowered air pollution emissions in an area with serious air quality problems – the Los Angeles Basin.

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[47] Expressed in tons of carbon in CO_2.

[48] National emissions of SO_2, NO_x, and CO_2 from buildings were about 9 million tons, 5 million tons, and 564 million tons (carbon equivalents), respectively.

[49] See http://www.dec.state.ny.us/website/dar/boss/ercindex.html.

Case Study 4-1: Post Office in Marina Del Rey Improves Air Quality

This case study demonstrates how innovative energy systems can reduce emissions. The area in which this facility is located – the Los Angeles Basin – is plagued with high ozone levels (smog). The project demonstrates one of the innovative technologies that produce electricity without any emissions. Incentive programs available in some locations from various sources can reduce the first costs of advanced technologies, resulting in very reasonable economics.

Project Description: The U.S. Postal Service (USPS) recently installed a large-scale photovoltaic (PV) system at its Marina Del Rey Processing and Distribution Center in Los Angeles. The center has over 400,000 ft^2 of floor area and high energy consumption and costs.

Approach to Sustainable Design: This facility is proactively seeking solutions to energy management, especially given California's volatile energy situation over the past two years. The USPS worked with Lawrence Berkeley Laboratory (in a technical advisory role), the Los Angeles Department of Water and Power (DWP), and DOE's FEMP to examine costs, energy savings, and key financial incentives from using PV systems at this site. The team determined that a rooftop solar power array would generate significant electricity to help offset peak demand utility costs.

The system was attractive not only because it saves energy but because it is also expected over its lifetime to reduce emissions: 2600 lb of NO_x emissions and 4075 tons of CO_2, equivalent to removing emissions from over 1000 cars or planting over 200,000 trees. The USPS is also considering PV for other postal facilities.

Sustainable Features: The PV technology installed at the facility consists of a 127-kW system from 845 modules that are lightweight and integrated in the building's roof over an existing roof membrane. The solar array is 50 ft by 300 ft and covers most of the facility's flat roof. The system produces clean power silently and is not visible to people on the ground.

The PV system uses silicon technology to convert sunlight directly into electricity. The output from the PV modules is direct current, which is converted to the required alternating current using an inverter and transformer. The system allows the current to be directly connected to the building's electric service panel. In addition to producing electricity, the PV panels provide R-20 value thermal insulation to decrease the building's energy consumption and reduce heating and air conditioning costs. The panels also extend the roof's life by protecting the roof membrane from ultraviolet rays and thermal conditions.

The system is linked to a new energy management system that monitors power output from the solar cells. When the system detects a decline in power output, for example, during cloud cover, it automatically modifies the operation of the building's chiller to compensate without affecting employee comfort.

Financial Considerations: The system's original first cost was about $1 million. The Los Angeles DWP provided a $684,000 rebate, and FEMP provided a Distributed Energy Resources Grant of $125,000. The net system cost to the USPS was about $226,000. The estimated annual cost savings are $25,000 to $28,000, resulting in a simple payback period of about 8 years.

Sources: Personal communication with J. Lin, PowerLight Corporation, Berkeley, CA; FEMP (2002).

4.2 Reduced Volumes of Solid Waste

The United States produces more than 230 million tons of municipal solid waste per year, consisting of paper, yard waste, plastics, metals, etc.[50] The 30 to 35 million tons of construction, renovation, and demolition waste that U.S. builders produce include wood (27% of total) and other materials such as cardboard and paper; drywall/plaster; insulation; siding; roofing; metal; concrete, asphalt, masonry, bricks, and dirt rubble; waterproofing materials; and landscaping materials (DOE 2002). As much as 95% of building-related construction waste is recyclable, and most materials are clean and unmixed (DOE 2002).[51]

In addition, building occupants produce municipal solid waste every day, in the form of used paper, plastic and glass containers, food waste, etc. Much of this can be recycled.

Several sustainable design principles reduce waste, which in turn reduces the strain on landfills. In addition, using recycled materials in building construction encourages development of new industries that produce recycled products, further reducing waste disposal needs and the use of virgin materials.

The main sustainable design principles that reduce waste include the following:

- **Storage and collection of recyclables.** The building design should provide space for collecting and storing materials such as paper, glass, plastic, and metals that will be recycled.
- **Construction waste management.** During construction, the contractor can recycle or productively use construction, demolition, and land-clearing wastes and divert these wastes from landfill disposal.
- **Recycled content.** Designers can select environmentally preferable materials that include recycled materials. (Designers should use standards developed by government agencies or other reliable sources.)
- **Waste prevention.** Designers can eliminate unnecessary finishes and make choices that use standard-sized or modular materials. In addition, designers should consider product durability in the design process. When products need to be replaced less frequently, less demolition waste is produced and fewer virgin resources are needed for replacements.

Case Study 4-2 describes how both the volume of waste and construction costs were reduced through an effective construction waste management program.

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[50] http://www.epa.gov/epaoswer/non-hw/muncpl/facts.htm.

[51] Original sources cited in DOE (2002) include *First International Sustainable Construction Conference Proceedings*, "Construction Waste Management and Recycling Strategies in the U.S.," Nov. 1994, p. 689; *Fine Homebuilding,* "Construction Waste," Feb./Mar. 1995, pp. 70-75; National Association of Home Builders, *Housing Economics*, Mar. 1995, pp. 12-13; and *Cost Engineering*, "Cost-Effective Waste Minimization for Construction Managers," Jan. 1995, Vol. 37/No. 1, pp. 31-39.

Case Study 4-2: Construction Waste Management and Other Recycling Measures Reduce Costs and Waste at EPA's New England Regional Laboratory

This case study demonstrates that using construction waste management, other recycling efforts during construction, and central recycling during building operation not only reduces the strain on local landfills but lowers construction costs.

Project Description: The New England Regional Laboratory (NERL), located in North Chelmsford, Massachusetts, is one of ten EPA regional laboratories that conducts environmental monitoring, analytical support, and data assessment. The 71,000-ft^2 building incorporates an environmental testing laboratory, as well as office and meeting spaces. This facility won a "Closing the Circle" Award and a U.S. Green Building Council LEED Gold Rating.

Approach to Sustainable Design: The new laboratory, which opened in September 2001, was designed and built using sustainable principles. The lab was supported by government agency sustainability advocates, GSA, and EPA, as well as a sustainability-conscious developer and contractor. The goal was to use the best commercially available materials and technologies to minimize consumption of energy and resources and maximize use of natural, recycled, and nontoxic materials.

The design construction team diverted more than 50% of its construction and demolition debris from the waste stream by recycling, processing excavated rock outcroppings into crushed stone that was also used on site, and reusing furniture and laboratory equipment from the former facility to furnish the new building while redistributing unused supplies to other buildings and organizations. The facility used fly-ash content concrete and many other recycled-content materials (insulation, carpet, floor tiles, mulch, compost made from yard trimmings or food waste, and recycled plastic benches and picnic tables).

Sustainable Features: The team maximized the use of natural site features, such as solar energy, natural shading, and drainage. The team's principal goals were achieving energy efficiency and maximizing renewable energy sources, so they incorporated a wide range of technologies and strategies, including lighting controls, skylights, light tubes, extra insulation, high-efficiency chillers and motors, green power, and PV awnings that supply 2 kW of electricity to the electric grid. Water-efficiency measures included Xeriscape concepts for landscaping, an onsite well for laboratory uses, and low-flow sinks with electronic sensors.

Commercial power is provided by Green Mountain Power of Vermont via 100% renewable energy sources. Green Mountain Power has committed to generating or purchasing wind-powered electricity that matches the electrical consumption of NERL, an estimated 2 million kWh per year. Using green power will reduce pollution by an estimated 3.46 million lb/yr of CO_2, 17,600 lb/yr of SO_2, and 6,200 lb/yr NO_x over conventional power sources.

Financial Considerations: The project team documented the cost savings from the construction waste management program. A concerted effort was made to minimize construction debris and to maximize recycling and reuse of anything that would become a waste stream. The team hired Graham Waste Services, a licensed hauler and processor of recyclables and solid waste.

Any waste that was generated during construction was carefully segregated into separate, clearly labeled bins that Graham Waste Services supplied. Bins were checked regularly for extraneous materials that could contaminate any of the loads. The estimated amounts of materials recycled during construction, the percent of the total waste stream recycled (by volume), and the associated cost savings (resulting from avoided disposal costs) were as follows:

- Clean wood: 330 cubic yards, 21% of the recycled waste stream volume, for a $2200 savings
- Cardboard: 10 cubic yards, 6% of the recycled waste stream volume, for a $250 savings
- Gypsum wallboard: 210 cubic yards, 13% of the recycled waste stream volume, for a $1400 savings
- Metal: 90 cubic yards, 6% of the recycled waste stream volume, for a $600 savings
- Concrete: 80 cubic yards, 5% of the recycled waste stream volume, for a $5760 savings
- Total savings: $10,210.

Note: In addition, 780 cubic yards of general refuse were recycled, but this did not lead to any cost savings.

Sources: Personal communication with B. Beane, EPA Region 1 in North Chelmsford, Massachusetts; and the documentation supporting the White House Closing the Circle Awards 2002 Nominations for Recycling, Affirmative Procurement, and Model Facility Awards.

4.3 Decreased Use of Natural Resources and Lower Ecosystem Impacts

Many sustainable design principles help reduce impacts on natural resources and ecosystems. Some key examples are as follows:

- Sustainable siting approaches consider alternatives to greenfield construction, including using existing facilities (e.g., urban redevelopment) and brownfield sites, and avoid building on prime agricultural land, floodplains, and habitats for threatened species or near wetlands, parklands, and cultural or scenic areas. The principles also include designing to reduce potentially detrimental conditions, such as slopes that can erode; avoiding adverse impacts on adjacent properties; and carefully considering the building placement amid existing trees on the site. Sustainable siting may also consider reducing the building's (or the site's) footprint to preserve the amount of open space. These measures
  - Protect threatened species, wetlands, cultural areas, and pristine natural areas
  - Remediate contaminated land (when a brownfield is used)
  - Preserve soil resources, trees, and open space in already developed areas.

- Siting near public transportation involves locating the facility near rail stations or bus lines and providing covered, wind-sheltered seating or waiting areas for public transport. Use of public and alternative transportation also can be fostered by installing bicycle storage and showers, alternative-fuel refueling stations, and preferred parking for carpools. In addition to reducing

air pollution from personal vehicles, these measures
  - Reduce land disturbance for new roads
  - Use less material for new roads.

- Erosion and sedimentation control, stormwater management, and sustainable landscaping involve developing a sediment and erosion control plan to prevent soil loss during construction, using natural water management approaches instead of traditional sewers, and designing a self-sustaining landscape. This approach can involve planting watershed buffers; using drought-resistant plants native to the region; avoiding plants needing chemical treatment and fertilizers or causing allergic reactions; designing natural drainage systems; and using techniques that allow water infiltration through surfaces (e.g., using porous paving surfaces for parking lots), which allows stormwater to filter through plantings and soil. These measures
  - Prevent sedimentation of streams
  - Reduce dust and particulate matter emissions during construction
  - Reduce disruption of natural water flows
  - Reduce runoff into natural water systems
  - Restore natural plant species to the region.

- Light pollution reduction is achieved by reducing dependence on high-wattage electrical lighting at night by using solar lighting and light-colored or reflective edges along driveways and walks and by designing night lighting to prevent direct-beam illumination from leaving the building site. These measures preserve nighttime habitats for nocturnal species.

- Water reduction measures include using low-flow faucets and showerheads, and improved fixtures and fittings that reduce water use (e.g., pressure-assisted or composting toilets and no-water urinals); low-water landscaping; improved cooling towers that use closed-loop cooling approaches; captured rain water for landscaping, toilet flushing, and other appropriate uses; and treatment and use of graywater, excess groundwater, and steam condensate. The water-efficiency and sustainable siting approaches for the prototype building, described in Section 2.1 and 2.2, which included use of low-flow faucets, no-water urinals, dual-flush toilets, and sustainable landscaping, would save over 233,000 gallons of water annually (equal to 70% of the base case building's consumption, including water used both inside the building and outside for landscape maintenance). Water reduction measures in buildings
  - Decrease extraction of potable water from groundwater reserves (e.g., aquifers), water bodies, and reservoirs
  - Reduce strain on aquatic ecosystems in water-scarce areas
  - Preserve water resources for wildlife and agriculture
  - Decrease impacts from wastewater treatment plants (e.g., effluent discharges).

- Energy efficiency measures not only reduce air pollution emissions associated with energy use (discussed in Section 4.1) but also decrease the need for nuclear and fossil fuels. These measures
  - Reduce the need for on-land disposal of nuclear waste, fly ash, and flue gas desulfurization sludge from power plants
  - Reduce habitat destruction and other environmental impacts from fuel extraction processing and transportation (e.g., coal mines typically disturb large tracts of land).

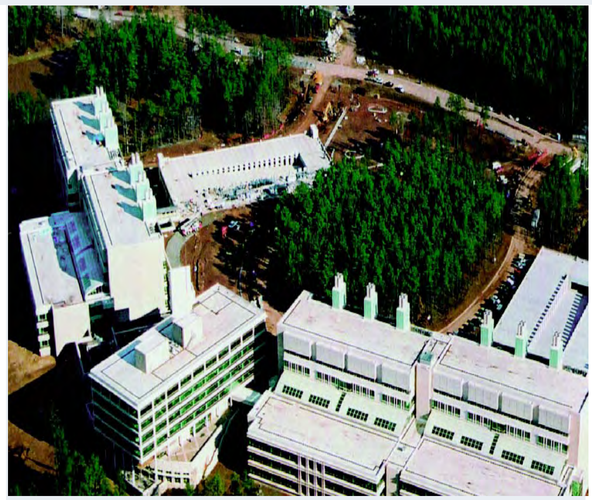
- Rapidly renewable materials (e.g., bamboo, cork, and wheat straw boards) and certified wood
  - Reduce the use and depletion of long-cycle renewable materials
  - Improve forest management and biodiversity.

- Design for reuse means designing a flexible building that can have many uses and that can be reconfigured in the future as needs change. As time progresses, this practice should reduce the need to demolish old buildings and construct new ones. These measures lower resource consumption (e.g., building materials such as steel, concrete, and glass, which are energy-intensive commodities).

Case Study 4-3 describes the efforts undertaken to develop a new multibuilding campus in a way that minimized disruption of the natural environment.

Case Study 4-3: EPA's Campus Protects Natural Resources at No Additional First Cost

This case study shows how a state-of-the-art lab and office complex can be a "model for environmental stewardship" without increasing costs. By forming a multidisciplinary design team and integrating environmental principles into the value engineering process, EPA created a 100-year building with estimated 40% energy savings, 80% construction waste recovery, 100% stormwater treatment through native plants and wetlands on site, daylight in offices, clean indoor air, flexible labs, and more – all with no extra budget for building "green." The case also shows that conserving energy and water, using a low-impact site design, minimizing materials, and making other substantive choices have clear economic benefits and that sustainable design features with little financial payback can be afforded by making tradeoffs in other areas.



Project Description: The laboratory/office complex is located on over 130 acres of land in Research Triangle Park in central North Carolina. The new facilities have one million gross square feet of floorspace, including 635,000 net square feet of office and laboratory space for 2200 employees. The complex has four 5-story lab buildings, connected by three 30-foot atria to three 3-story office buildings. The main building also includes a central five-story office tower with cafeteria, conference center, auditoriums, and a library. The lab and office buildings are situated alongside a lake and follow the curve of the shore. The campus also includes a computer center and child-care facility.

Approach to Sustainable Design: Because it had not undertaken a project of this magnitude before, the EPA looked to the GSA and the Army Corps of Engineers for design assistance and construction management. Working with these agencies and the chosen architecture firm (Hellmuth, Obata + Kassabaum), the Clark Construction Group, and the Gillbane Building Company (a GSA contractor providing construction administration and quality assurance), EPA developed a team approach to defining environmental objectives and tracking progress toward them. Project leaders made a clear commitment to design and build a green building. They felt the EPA facility should symbolize the EPA's environmental mission. Green design criteria were written into the solicitations for the architectural and engineering services, the Program of Requirements and the contracts. Working together, green advocates, architects, engineers, and building users developed innovative approaches after systematically reviewing a wide range of options. At every step along the way, the team raised questions about and re-evaluated assumptions.

Sustainable Features: The sustainability of the building's and site's designs was studied in depth. The designers used natural methods for landscaping and stormwater treatment. To protect more than 9 acres of onsite wetland areas, designers used a buffer zone about 100-feet wide along the lake edge and allowed no development except for a network of walking and jogging trails. A tree survey resulted in redesigned roads, saving large oak trees that have been there since the early part of the 20th century. Also, the size of the road was decreased from four to two lanes to minimize disruption to the natural areas and reduce costs. A parking structure was built instead of disrupting acres of natural woodland for an onsite paved parking lot.

The building design includes sunshading, tight building envelopes, high-performance glass, a high level of daylighting, occupancy sensors and daylight dimming, high-efficiency chillers and boilers, variable frequency drives, an outside air economizer cycle, and high-efficiency fume hoods. The buildings also used low-flush toilets and urinals, low-flow aerators and showerheads, and water-efficient cooling towers. Many recycled materials were used: recycled-content asphalt, rubber flooring, ceramic tiles, insulation, wood fiberboard gypsum wallboard, and more. Materials were also selected to be durable (the building was designed to last 100 years). About 80% of all construction waste was recycled, which diverted about 10,000 tons of material from local landfills. Careful attention was paid to ventilation, selection of materials and finishes, and construction procedures to minimize air quality degradation inside the building.

Financial Considerations: Throughout the project, the team examined the cost of green design and the cost of various options. For example, multiple skylight options for the atrium in the buildings were considered, and the options' first costs and energy costs over a 20-year life were compared. EPA also chose to engage in focused value engineering reviews. Although value engineering is often seen as the enemy of good design in general and green design in particular, EPA transformed the traditional value engineering process into an exercise in balancing cost, function, and environmental performance by including designers and sustainability advocates on the value engineering review team and encouraging interdisciplinary brainstorming.

The value engineering process was especially important at this site because during the appropriations process, the U.S. Senate asked EPA to review the project again to see if the total cost could be reduced. Working with the designers, the value engineering team not only reduced the total project cost by about $30 million (resulting in a final cost of $225 million) but also produced a greener building. Given the pressure to reduce costs, many of the environmental features that required a first-cost increment (e.g., the above-ground parking garage designed to minimize disruption to 15 acres of natural woodlands) could have easily been eliminated. However, the team reviewed the project budget as a whole and chose to eliminate other features that were not considered critical to meet their environmental goals. For instance, over 200 doors were eliminated to save costs. To lower the cost increment of the above-ground parking garage, the amount of onsite parking was reduced by 25%, and alternative transportation methods were encouraged. In effect, the design team put a higher value on the 15 acres of natural woodland than on building design features they considered less important to quality of life.

Some of the environmentally motivated strategies that reduced cost included the following:

- Replacing four-lane roads with two-lane roads (and burying the electrical and communication lines under the road) greatly decreased the road and utility footprint, preserved the site woodlands and wetlands, reduced construction cost by $2 million, and lowered maintenance and repair costs.
- Replacing curb and gutter and oil-grit separators with grassy swales and water quality and bio-retention ponds reduced construction costs by $500,000.
- Changing the atrium skylight from all glass to one-third glass, one-third insulated translucent panels, and one-third solid panels to improve energy performance, indoor environmental comfort, and light quality saved $500,000 in construction costs and $50,0000 in annual energy costs.
- Installing 250 specialized fume hoods and exhaust systems that reduce total air flow demand by 50% and eliminating dozens of fans lowered construction cost by $1.5 million and annual energy costs by $1 million.

When benchmarked against other laboratory/office buildings, the annual energy use in the facility was estimated to be 40% lower than a similar facility, with a savings of more than $1 million per year.

Sources: Communication with C. Long and P. Schubert, EPA's Research Triangle Park; EPA (1997, 2001); and DOE's High Performance Buildings Database at http://www.eere.energy.gov/buildings/highperformance/case_studies/overview.cfm?ProjectID=30.

5.0 Strengthening the Business Case: Research and Data Needs

The research results and case studies that were presented in the preceding sections show that a strong business case for sustainable design and construction can be made today. Case studies described in Section 2 indicate that a well-designed building, which integrates sustainable design features in the early stages of design, can be built at about the same cost as a more typical building without those features because creative building design teams can incorporate sustainable features by reducing costs in other parts of the project. Even when first costs increase slightly, lifecycle cost reductions and short payback periods can make sustainable design very cost effective. A number of studies also show that sustainable buildings have positive impacts on occupants. Because the annual salary and benefit costs of building occupants far outweigh the annualized capital costs or the yearly costs of energy and O&M, occupant productivity gains can have a considerable impact on business costs.

Other stakeholders, such as neighbors and local and state governments, may also realize benefits such as increased protection of local natural resources, lower pollution loadings, better regional employment opportunities, and lower infrastructure needs (e.g., water and waste treatment facilities). These, in turn, can result in economic benefits to the building owner/operator in the form of easier siting of the next facility, less time to deal with complaints from the neighbors, and other indirect benefits. For government agencies, the "public good" value associated with these benefits should, in theory, be more important than it is in the private sector. Unfortunately, some of these benefits are supported mainly by a few research studies or anecdotal evidence.

Table 5-1 summarizes the status of the business case information in the various cells of the matrix presented in Section 1 (also presented in more detail in Appendix A).

The arguments supporting sustainable design will gain strength as more data and information are collected on the effects of sustainable design and construction on first costs; annual energy and other operating costs; occupant health, productivity, and well-being; environmental impacts; and other social and business impacts. Some of the areas for which data gathering may prove useful to the business case are as follows:

- **First costs.** Because projects evolve over time, there is usually no clearly defined "before" and "after" picture that would allow the costs of various features that were added or taken out of the design to be estimated. Case studies aimed at tracking cost estimates as the project evolves would be useful. First-cost information could be more widely disseminated by adding more case studies and detail to the cost information in databases such as DOE's High Performance Buildings Database. In addition, for many types of sustainable design features, very little generic cost information has been gathered. For sustainable materials, some reliable data have been collected into databases such as the Building for Environmental and Economic Sustainability developed by the National Institute of Standards and Technology[52] but further work to develop similar databases for other types of sustainable design features may be warranted. The ability to examine various classes of features (materials, energy efficiency, water, etc.) through one access point (e.g., a single website) could be very useful.

[52] Available at http://www.bfrl.nist.gov/oae/software/bees/please/bees_please.html.

Table 5-1. Status of Business Case Information

Category			Environmental Benefits
Sustainable siting	Some information is available on the cost and cost savings associated with siting approaches. This study estimated cost savings associated with "natural" landscaping (resulting from reduced water and fertilizer consumption). More data like this could be gathered through case studies or analysis of vendor information.	This study found no comprehensive research done on the value society places on sustainable siting. However, some survey work or other research may have been done (e.g., in an environmental impact statement process) to examine benefits of specific sustainable design strategies, such as siting on brownfields.	No comprehensive research has been done on the environmental benefits of siting strategies. These would be site-specific. It would be feasible to estimate benefits such as CO_2 and air pollution benefits of lower energy use due to better passive solar strategies.
Water efficiency	Some information is available on the cost and cost savings of various water-saving strategies. This study estimated first costs and cost savings associated with specific water-efficiency technologies, but a wider range of technologies could be investigated. The water and cost savings in this study are based on theoretical estimates; no water monitoring studies have been incorporated into the business case report to date.	Impacts of building water consumption on current and future water supplies have not been studied in any comprehensive way (according to the research done for this study). Information on local water supply impacts may be available in cases where environmental impact statements must be completed.	This study estimated impacts on water consumption of some specific technologies. A wider range of technologies could be investigated (such as those applicable to larger buildings than those examined in this study). Also, projections of Federal facility water use and potential for reduction using sustainable design strategies would be useful.
Energy efficiency	Costs for a wide variety of energy-efficiency measures are available from various sources. This study estimated first costs and annual cost savings associated with a combination of those technologies. Some case study information has also been gathered. Further work would involve gathering costs of a wider range of technologies, especially those that should be used in larger building. Also, most of the estimates in this document have been based on models, not measured energy savings. More measured data could be gathered.	Some research results show positive effects on building occupants of certain building features, such as daylighting, which also reduce energy consumption. Although thermal comfort effects on productivity have been studied, data are sparse on the impact of particular HVAC systems and other energy-efficiency measures on occupants. One exemption is the study by Loftness et al. (2002), which compiled research results on occupant benefits of underfloor HVAC systems. This area of research might be of interest to the energy-efficiency community.	The direct air pollution and CO_2 emission impacts of energy-reducing strategies are fairly easy to estimate. Other environmental impacts of energy efficiency are site-specific and more difficult to estimate.

Category			Environmental Benefits
Sustainable materials	Some databases of sustainable materials exist (e.g., the National Institute of Standards and Technology maintains the Building for Environmental and Economic Sustainability – BEES – database). This study estimated first costs and estimated cost savings associated with specific sustainable materials.	Some research results indicate that the use of low-emitting material such as carpeting, paint, etc., can reduce occupants' illness symptoms.	The full lifecycle impacts of sustainable materials could be investigated. Some effort has been undertaken by various research groups to do this kind of work.
Indoor environmental quality	Some costs have been gathered in databases such as BEES (see above). Cost differentials for low-VOC paint are included in the document. Cost estimates of improved ventilation are available. Further refinement and data gathering may be warranted for other features related to indoor environmental quality.	Much research has been done in this area (see Appendix F), but gaps exist. Gaps could potentially be prioritized based on the business impact of the effects.	Very little coverage of this topic is in this document or elsewhere.
Commissioning and O&M	Quite a few case studies of building commissioning have been compiled by PECI. This document includes a very cursory examination of the costs and cost savings of commissioning and O&M.	Based on the limited search for information conducted for this study, it appears that little work has been done to estimate the positive impacts of commissioning and O&M on building occupants. This topic has been discussed only qualitatively in this business case report. This is a potentially important area for business case research because occupant health impacts have potentially large financial consequences.	Estimating air pollution impacts of reducing energy use through commissioning and O&M is feasible. General information on energy savings associated with commissioning and O&M has been included in this document.

- **Annual energy cost data.** Most information about cost savings associated with sustainable buildings is based on estimates made in the design phase. For instance, energy savings are modeled using tools such as Energy-10 and DOE-2 (discussed in Section 2 and Appendix B). But, once built, the building may not perform as simulated. Meters can be used to measure actual performance and compare that against the modeled results, but metering studies can be costly and often are not performed because of budget constraints. Even when meters are present, some building operators report that they do not have the time and resources to analyze the data. This document provides information from a few case studies where actual performance has been measured and analyzed. A more widespread program to monitor energy consumption and costs by end use in both sustainable and traditional buildings could bolster the business case for sustainable design in Federal facilities.

- **Non-energy operating costs.** In addition to energy costs, annual water/sewer costs as well as general maintenance and repair costs could be monitored in sustainable buildings to help determine whether these costs are lower than those in their traditional counterparts.

- **Occupant benefits.** A number of studies indicate that sustainable buildings improve occupant productivity and have other positive impacts that can affect the bottom line, but more research is needed to quantify these effects in a way that allows decision makers to translate them into cost savings for every type of building. The Center for Building Performance and Diagnostics within the School of Architecture at Carnegie Mellon University has collated a large body of research into a tool called the Building Investment Decision Support (BIDS). BIDS allows a user to generalize the results of particular research studies to estimate potential benefits at the user's facility. Given the differences between the buildings studied in the research and each user's specific building, BIDS can provide only a hypothetical estimate of dollar benefits. More research on building occupants' health, satisfaction, and productivity in a wide range of buildings would help strengthen the business case. In particular, a better understanding is needed on how to quantify impacts on the productivity of "knowledge workers." In addition, the sustainable design community would benefit from more research that links specific sustainable design features to the corresponding occupant benefits.

- **Other benefits to the building owner and the public.** Aside from the impacts of indoor environmental quality on occupants, very little research has been conducted on the social impacts of other aspects of sustainable design. Many hypothesized relationships between sustainable design features and impacts on both occupants and society at large described in the previous sections are supported by only a few studies or by anecdotal evidence. Data-gathering methods could be developed to investigate the validity of the following arguments for sustainable design:
  - Employee turnover is substantially lower in sustainable buildings.
  - Green buildings experience lower occupant complaints and less on-call maintenance costs.
  - Property values increase in the vicinity of green buildings.
  - Sustainable building improves the market for recycled products.
  - Green buildings are a factor in attracting the most desirable employees.

  These factors may be as important to the business case as first costs and energy savings, so further research to gather data on these topics through surveys and other means may be warranted.

- **Environmental benefits.** Some of the potential research activities on environmental benefits of sustainable design in Federal facilities might include the following:
  - Develop a better profile of the environmental impacts of Federal facilities
  - Benchmark "best practices" with regard to environmental impacts, so comparisons can be made across facilities
  - Improve monitoring and analysis of energy and water consumption in Federal facilities, especially new, green buildings and quantitatively assess the environmental improvements (e.g., reductions in energy, air emissions, and water consumption)
  - Share lessons learned and case studies that quantify environmental improvements
  - Continue to track studies assessing the environmental impacts of buildings and methods to place economic values on environmental improvements.

In November 2002, FEMP convened a workshop of individuals knowledgeable about the business case for sustainable design from various government agencies, academia, and the private sector.

The purpose was to discuss data and research needed to make a stronger business case for sustainable design (FEMP is expected to publish a report on this workshop in the near future). Small groups of workshop participants discussed research needs in three areas: direct cost savings associated with sustainable design and construction, occupant productivity and well-being, and strategic business considerations. Some of the recommendations of the participants, summarized in Table 5-2, overlap with and build on the suggestions described above.

Table 5-2. Key Recommendations from Participants in the Sustainable Design Business Case Workshop

		Strategic Business Considerations
• Gather cost data (e.g., dollars per ft^2, normalized by building type and location) for many sustainable design projects so that analysts can estimate statistically significant differences in first costs between traditional and sustainable buildings • Use DOE's High Performance Buildings website to compile case studies • Understand the differences between the costs for incremental improvements that marginally improve a building's environmental performance versus costs for sustainable buildings derived from integrated design • Develop consistent protocols for data collection, reporting, and use	• Develop a better understanding of productivity and how it can be measured for a whole variety of job types, including knowledge workers, as well as the impacts of sustainable design and construction on productivity • Better define the critical building features (both sustainable and other features) that impact health, well-being, and productivity to be included in controlled studies • Focus on causal links between building features and health (e.g., disease transmission) using controlled studies (perhaps using methods, data, and results from other fields of research) • Develop a more definitive understanding of the relationship between daylight; natural ventilation; and views on health, well-being, and productivity • Conduct cross-sectional studies of high-performance buildings compared with conventional buildings using survey tools	• Identify methods to better understand risk and liability, occupant health effects, employee retention, and other key impacts of sustainable design • Develop a common standard for assessing environmental (broadly defined) impacts of sustainable facilities • Develop a method to allow all levels of managers to build their own business case for sustainable projects (within the context of their agencies and management priorities) • Work with a broad range of stakeholders to develop ways to better understand the strategic benefits of sustainable design and consider ways to study the market-transforming effects of systems such as LEED

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Appendix A: Matrix of Benefits of Sustainable Design

This appendix provides information on the benefits of various sustainable design features. The benefits are listed in the matrix (Table A-1) for each sustainable design feature. The features are categorized into six primary categories:

1. Sustainable siting
2. Water efficiency
3. Energy efficiency
4. Sustainable materials and resources
5. Indoor environmental quality
6. Commissioning and operation & maintenance (O&M).

These correspond closely to the categories in the Leadership in Energy and Environmental Design (LEED™) rating system and the *Whole Building Design Guide*[1] discussed in Section 1 of the main body of this document. Thus, this matrix combines the "triple bottom line" benefits framework with six principal elements of sustainable building design. Some of the benefits accrue to the facility owner, and other benefits accrue to other parties such as employees, local governments, the local community/economy, or the public at large. When applicable, those are designated in the table.

Although the list of benefits is extensive, it may not be completely comprehensive. Some of the benefits of sustainable design will be discovered as more experience is gained with living and working in sustainable buildings.

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[1] See http://www.wbdg.org/index.asp.

Table A-1. Possible Benefits of Sustainable Design, by Feature

	Benefits Category		
			Environmental
Sustainable Siting			
Site selection. Analyze alternatives, including use of existing facilities. Do not build on prime agricultural land, flood-plains, and habitats for threatened species; near wetlands; or on parklands. Consider urban redevelopment and brownfield redevelopment sites (which require cleanup).	*Facility*: • Lower site preparation costs • Potential for reduced costs of litigation and time delay (e.g., because threatened species are not present not at the site) *Local government*: • Lower infrastructure development costs to support existing rather than greenfield sites *Local economy:* • Reduced tourism losses	*Society:* • Preservation of natural areas, agricultural land, and parkland for future generations	*Society:* • Decreased use of virgin resources • Protection of threatened species and wetlands • Remediation of contaminated land (when brownfield is used) • Reduced erosion and flood damage • Reduced impact on fisheries and forests
Site analysis and harmonious building-site relationship. Inventory and analyze the ecological context, urban and historical context, and natural and cultural attributes. Organize mass, orienta-tion, topography, and outdoor spaces to employ passive solar principles; provide outdoor spaces; etc. Design to reduce potentially detrimental conditions, such as slopes that can erode. Avoid adverse impacts on adjacent properties. Carefully consider the placement of existing trees on site.	*Facility*: • Possible reduction in first costs (reduced size and cost of mechanical systems) • Reduction in operating costs (fuel costs) *Local government:* • Elimination of unnecessary infrastructure expenditures due to good assessment of site resources	*Society:* • Improved aesthetic and functional quality of site and building for both occupants and neighbors	*Society:* • Reduction in energy consumption and emissions due to optimal orientation, etc. • Conservation and restoration of ecological and cultural resources • Reduced negative microclimate and environmental effects in local vicinity
Facilitation of alternative transpor-tation use. Locate facility near rail station or bus lines. Provide covered, wind-sheltered seating or waiting areas for public transport. Provide bicycle storage and showers. Install alternative-fuel refueling stations. Provide preferred parking for carpools.	*Facility*: • Slightly lower capital cost due to reduced parking lot size (could be offset by additional costs for showers, and refueling stations) *Employees:* • Potentially lower commuting costs (using public transport rather than personal cars)	*Employees:* • More transportation options	*Society:* • Lower energy use and air pollution from vehicles • Reduced land disturbance for new roads

	Benefits Category		
			Environmental
Erosion and sedimentation control and stormwater management. Develop sediment and erosion control plan. Prevent loss of soil during construction. Prevent sedimentation of storm sewer or receiving streams. Plant watershed buffers. Allow infiltration via porous surfaces. Filter stormwater through plantings and soil. Use natural drainage systems.	*Facility*: • Decreased cost of storm drainage construction by using more natural methods • Reduced cost of landscaping after construction is completed (because topsoil is saved) *Local/state government*: • Reduced cost of stream cleanup and water treatment plants	*Neighbors/local community:* • Less disturbance during construction	*Society:* • Less loss of soil during construction • Prevention of sedimentation of storm sewers or receiving streams • Reduced dust/particulate matter during construction • Less disruption of natural water flows • Reduction of runoff into natural water systems
Reduced site disturbance during construction. Limit site disturbance around the building perimeter, curbs, walkways, and main utility branch trenches. Reduce the development footprint to exceed open space requirements in local zoning rules.	*Facility:* • Potentially decreased cost of clear-cutting and subsequent relandscaping • Decreased site infrastructure costs	*Neighbors/local community:* • Less disturbance during site preparation • Retention of vegetation and scenic vistas • More greenspace for use by occupants and/or community	*Society:* • Preservation of trees and other vegetation • Increased habitat for natural species; biodiversity
Sustainable landscape and exterior design. Use self-sustaining landscape design and site maintenance procedures. Restore habitats. Use plants native to the region. Consider drought-resistance plants. Avoid plants needing chemical treatment and fertilizers or causing allergic reactions. Consider using "green roofs."	*Facility:* • Reduced maintenance costs, water use, fertilizer, and fossil fuel use due to "naturally manicured" landscaping • Possibly decreased heat/cooling loads due to vegetated roof	*Neighbors/local community:* • More aesthetic natural exterior appearance of building to neighbors and occupants	*Society:* • Reduced impact on microclimate • Lower threat of negative ecological impacts resulting from use of non-native plant species
Light pollution reduction. Allow no direct-beam illumination to leave building site. Use light-colored or reflective edges along driveways and walks to reduce dependence on high-wattage electrical lighting at night. Use solar lights. Use security lighting with motion sensors to reduce use of lights at night.	*Facility:* • Possibly lower cost of electricity for lighting (depending on design)	*Neighbors/local community:* • Less disturbance to natural night sky conditions • Improved security of building	*Society:* • Preservation of nocturnal habitat

	Benefits Category		
			Environmental
Water Efficiency			
Water use reduction. Use captured rainwater for landscaping, toilet flushing, etc. Treat and re-use graywater, excess groundwater, and steam condensate. Use low-flow fixtures and fittings (pressure-assisted or composting toilets, waterless urinals, etc.) and ozonation for laundry. Use closed-loop systems and other water reduction technologies for processes.	*Facility:* • Decreased water costs • Potential for O&M savings *Local government:* • Less wastewater treatment infrastructure needed (fewer taxes to pay for infrastructure)	*Society:* • Preservation of natural water resources for future generations	*Society:* • Reduced use of potable water • Reduced generation of wastewater; lower discharge to natural waterways
Energy Efficiency			
Space layout. Fully utilize opportunities for passive solar heating/cooling. Optimize natural ventilation and daylighting. Enhance penetration of daylight to interior spaces. Provide inviting staircases to encourage their use rather than elevators.	*Facility:* • Diminished heating, cooling, and lighting loads and reduced energy costs • Increased operating efficiency due to right sizing of equipment • Possibly lower capital costs due to reduced size/cost of mechanical systems through more efficient design features, appropriate sizing, and optimal integration • Potentially higher occupant productivity due to daylighting *Society/utility companies:* • Avoidance of electricity generation and transmission/distribution construction costs	*Employees:* • Improved quality of interior space (a secondary benefit of many energy-efficient design features)	*Society:* • Lower electricity use, fossil fuel use, and air pollution/carbon dioxide (CO_2) emissions and other environmental impacts of electricity production and fossil fuel use • Decreased impacts of fuel production and distribution (for fuels used in the building or in production of electricity for the building)

	Benefits Category		
			Environmental
Building envelope. Design envelope to provide good thermal and moisture control while supporting passive solar and natural ventilation design strategies. Detail walls to provide best vapor barriers and low outside air infiltration.	*Facility:* • Diminished heating, cooling, and lighting loads and reduced energy costs • Increased operating efficiency due to right sizing of equipment • Possibly lower capital costs due to reduced size/cost of mechanical systems through more efficient design features, appropriate sizing, and optimal integration *Society/utility companies:* Avoidance of electricity generation and transmission/distribution construction costs	*Employees:* • Improved quality of interior space (a secondary benefit of many energy-efficient design features)	*Society:* • Lower electricity use, fossil fuel use, and air pollution/carbon dioxide (CO_2) emissions and other environmental impacts of electricity production and fossil fuel use • Decreased impacts of fuel production and distribution (for fuels used in the building or in production of electricity for the building)
Lighting and sun control. Use glazing to supply daylighting but control glare. Use roof monitors and high clerestory windows. Specify photocell-dimming sensors to adjust light. Use separate switches to turn off lights in individual areas. Use light shelves and other techniques to bring light deeper into the building. Supplement daylighting with high-performance lighting that improves visual quality while reducing electrical use. Use low-ambient lighting levels with task lights, where appropriate. Use occupancy sensors, dimmers, photocells, and lumen maintenance controls.	*Facility:* • Reduced electricity consumption/ costs • Lower cooling loads due to lower heat gains from electrical lighting; hence, reduced energy costs and lower capital costs for cooling system • Potentially higher occupant productivity due to daylighting and visual quality *Society/utility companies:* • Avoidance of electricity generation and transmission/ distribution construction costs	*Employees:* • Improved quality of interior space	*Society:* • Lower electricity use and the associated air pollution/CO_2 emissions • Decreased impacts of fossil fuel production and distribution

	Benefits Category		
			Environmental
Systems and equipment. Optimize mechanical systems to work with the building layout, orientation, envelope, etc. Consider HVAC zoning, distribution systems, heat recovery systems, modular boilers, and ice storage. Do not use chlorofluorocarbon/hydrofluorocarbon (CFC/HCFC) refrigerants. Develop integrated systems designs that consider interaction of systems with overall building layout, envelope, etc. Include efficient power distribution systems, electrical equipment, motors, transformers, etc. Consider use of raised floor and underfloor HVAC with personal controls	*Facility:* • Reduced energy costs • Reduced capital costs due to downsizing of equipment • Lower churn costs (if raised floor is used) • Better productivity (if personal controls are implemented)	*Employees:* • Improved occupant comfort	*Society:* • Lower electricity use and the associated air pollution/CO_2 emissions • Decreased impacts of fossil fuel production and distribution • Protection of the ozone layer (due to avoidance of CFCs/HCFCs)
Renewable energy. Consider using photovoltaic, solar heat and hot water, geothermal heat pumps, etc. Consider entering into green power or renewable credit contracts.	*Facility:* • Lower annual energy costs *Local economy:* • Potential for emerging businesses related to renewable energy	*Society:* • Promotion of market for renewable energy products	*Society:* • Lower electricity use and the associated air pollution/CO_2 emissions • Decreased impacts of fossil fuel production and distribution
Energy load management. Use energy management systems, monitoring, and controls to continuously calibrate, adjust, and maintain energy-related systems.	*Facility:* • Operational savings (can offset higher first costs) • Reduced capital cost of mechanical systems because control systems reduce the need for oversizing	*Employees:* • Improved comfort, health, and safety	*Society:* • Improved energy efficiency, hence lower electricity and fossil fuel use and lower emissions *Employees:* • Better indoor air quality

	Benefits Category		
			Environmental
Sustainable Materials and Resources			
Storage/collection of recyclables. Provide a system for collecting and storing materials such as paper, glass, plastic, and metals for recycling	*Facility:* • Possibly lower waste disposal costs *Local community:* • Local recycling business opportunities *Local government:* • Lower landfill construction costs	*Employees:* • Opportunity for building occupants to feel they are "making a difference," which can be an opening for other actions *Society:* • Expanded market for recycled and environmentally preferable products	*Society:* • Reduced strain on landfills • Reduced use of virgin natural resources
Building and resource re-use. Reuse building shell from existing buildings and fixtures from demolished buildings. Use salvaged/refurbished materials.	*Facility:* • Decreased first costs due to re-use of materials *Local government:* • Less waste disposal; lower need for new waste disposal facilities	*Society:* • Expanded market for salvaged materials	*Society:* • Reduced strain on landfills • Reduced use of virgin natural resources
Construction waste management. Recycle or productively use construction, demolition, and land clearing wastes. Divert these wastes from landfill disposal.	*Facility:* • Possible decrease in construction first costs due to lower waste disposal costs	*Society:* • Expanded market for recycled and environmentally preferable products	*Society:* • Reduced strain on landfills • Reduced use of virgin natural resources
Recycled content. Select environment-ally preferable materials that include recycled materials (use standards developed by government agencies or other reliable sources).	*Facility:* • Possible decrease in first costs of construction due to lower price of recycled materials (in some cases)	*Society:* • Expanded market for recycled and environmentally preferable products	*Society:* • Reduced strain on landfills • Reduced use of virgin natural resources

	Benefits Category		
			Environmental
Waste prevention. Use modular materials. Select products for durability. Eliminate unnecessary finishes and other products.	*Facility:* • Possible decrease in first costs of construction due to less use of materials • Longer lifetime of building and building features due to increased durability of materials used • Decreased operating costs (including replacement and waste disposal costs) by using more durable materials that need to be replaced less often	*Society:* • Less nuisance associated with landfills	*Society:* • Reduced strain on landfills • Reduced use of virgin natural resources
Local/regional materials. Obtain materials, whenever possible, from local resources and manufacturers.	*Local economy:* • Success of local businesses	*Local economy:* • Employment opportunities	*Society:* • Lower energy consumption and resulting air pollutant air emissions due to less freight transportation
Rapidly renewable materials (bamboo, cork, wheat straw boards, etc.); certified wood.	*Facility:* • Possible reduction of first costs *Society:* • Emerging businesses	*Society:* • Preservation of forests for future generations	*Society:* • Reduced use/depletion of long-cycle renewable materials; better forest management; biodiversity
Design for re-use. Design buildings for flexible uses so they can be reconfigured in the future as needs change.	*Facility:* • Lower lifecycle capital construction requirements • Lower churn costs	*Society:* • Less disturbance due to new construction	*Society:* • Lower resource consumption (on a lifecycle basis)

	Benefits Category		
			Environmental
Indoor Environmental Quality			
Indoor air quality. Control pollutant sources (from neighboring buildings, soil such as radon and methane, and excessive dampness). Use low-emission materials (paint, carpet, fabrics). Allow new materials to ventilate before occupancy. Include good ventilation systems and operable windows, where appropriate. Specify systems that feature economizer cycles. Consider underfloor air ducting. Use CO_2 sensors. Use control systems, including personal workstation control, if possible. Eliminate tobacco smoke.	*Facility:* • Organizational productivity improvements (reduced absenteeism) • Lower workman's compensation, disability, health, and liability insurance costs • Reduced threat of litigation *Employees:* • Lower health care costs to occupants	*Employees:* • Reduced adverse health impacts (especially respiratory disease/discomfort) • Improved personal productivity	*Employees:* • Better air quality inside the facility *Society:* • Reduced volatile organic compound emissions to the atmosphere due to use of low-emission materials
Good visual quality. Appropriately use windows, skylights, shading devices, and light shelves. Avoid glare. Combine ambient and task lighting. Use high-frequency ballasts. Give occupants adequate visual access to outdoors and to the organization of the building. Use pleasing surface colors and reflectivity.	*Facility:* • Reduced energy costs (by using daylighting)	*Employees:* • Satisfaction with work environment • Improved personal productivity	*Society:* • Lower energy use and emissions due to use of daylighting and energy efficient lighting
Noise control. Reduce noise at the source during design phase (e.g., through orientation, building layout, selection of mechanical, plumbing, and ductwork). Use acoustic buffers; floating floor slabs; and sound-insulated wall, floor, and ceiling penetrations. Achieve good room acoustics by configuring rooms, using white noise, etc.	*Facility:* • Lower cost of dealing with complaints	*Employees:* • Satisfaction with work environment • Improved personal productivity	
Systems controls. Provide maintenance staff and users with level of control over automated building systems appropriate to their level of technical expertise. Provide individual occupant controls when possible (in conjunction with underfloor systems)	*Facility:* • Possible decrease in operational costs • Decreased churn costs due to underfloor systems	*Employees:* • Thermal and visual comfort of occupants • Improved personal productivity	*Society:* • Decreased energy use and resulting environmental impacts due to better control of energy systems

	Benefits Category		
			Environmental
	Commissioning and O&M		
Commissioning and O&M. Use third-party assessments to ensure that the installed systems work as designed. Develop O&M manuals and train staff.	*Facility:* • Fewer equipment breakdowns and downtime costs • Lower lifecycle replacement costs • Reduced costs of dealing with occupant complaints	*Employees:* • Occupant satisfaction with building • Health/safety of building occupants	*Society:* • Lower energy consumption and air pollutant emissions *Employees:* • Better indoor air quality
Sustainable housekeeping and maintenance. Clean and maintain all building equipment to ensure proper functioning. Check for water leaks and make repairs. Check for signs of mildew and mold growth. Use nontoxic, natural cleaning/maintenance chemicals. Periodically or continuously monitor indoor air quality.	*Facility:* • Possibly lower operating expenses (e.g., reduced water consumption) • Less chance of sick building syndrome and associated legal costs.	*Employees:* • Improved indoor environ-mental quality • Better health of occupants	*Society:* • Reduced chemical influx into the environment (by using natural cleaning products) • Lower water use (due to leak monitoring)

Appendix B: Energy and Construction Cost Estimates[1]

This appendix describes the energy modeling used in the analysis presented in Section 2.2 of this document. The analysis showed that the combination of energy-savings features added to the prototype building had a savings-to-investment ratio of nearly 1.5 and an adjusted internal rate of return of almost 5%, which makes a compelling business case for sustainability.

Figure B-1 illustrates the main steps of the modeling process. As the figure shows, the modeling effort began with a characterization of a base-case building. This building, intended to represent a typical new Federal office building, was the basis against which the sustainable building was compared. The base-case building's energy use was then estimated using a building energy simulation model, DOE-2.1E. The base-case characterization and model assumptions are documented in Section B.1 of this appendix.

The sustainable building was defined in terms of a number of improvements made to the base-case building. A set of potential improvements was developed and simulated in another energy simulation model, ENERGY-10, which optimized for energy and lifecycle cost savings. This simulation provided information that allowed a final set of improvement options to be selected based on maximum energy and lifecycle cost savings. These options defined the sustainable building. This process is described in Section B.2 of this appendix.

The sustainable building was then simulated in DOE-2.1E to obtain energy-use estimates. These were compared with the energy-use estimates of the base-case building, and estimated energy savings and the associated incremental costs were calculated. The simulation of the sustainable building is described in Section B.3, and the results of the energy-savings and cost calculations are described in Section B.4. Section B.5 explains some of the differences between DOE-2.1E and ENERGY-10.

B.1 Base-Case Building Characterization

B.1.1 Energy Design Standard

The study used the American Society of Heating, Refrigerating, and Air Conditioning Engineering (ASHRAE) standard 90.1-1999 as the energy design standard or code for the base-case building and ASHRAE 90.1-1999, Table A-13, to implement the base-case building envelope parameters. The HVAC equipment in the base case was modeled at the minimum efficiency levels according to ASHRAE 90.1-1999, Tables 6.2.1B and 6.2.1E. The supply fan energy was modeled separately by breaking down the energy-efficiency ratio (EER) and coefficient of performance (COP) into its components. For some building characteristics not specified in ASHRAE 90.1, such as the building operation schedules and HVAC system types, assumptions were made based on data from several sources including the "Commercial Buildings Energy Consumption Survey" (Energy Information Administration 1995), the Proposed Appendix G to ASHRAE 90.1-2001, and general engineering practices.

B.1.2 Construction Cost Estimating for the Base-Case Building Design

The purpose of the construction cost estimate for the overall base-case building was to set a reasonable order-of-magnitude cost for use in the lifecycle cost calculations. The estimating method was parametric –

[1] This appendix was written by D. Winiarski, S. Shankle, J. Hail, and B. Liu, Pacific Northwest National Laboratory, and A. Walker, National Renewable Energy Laboratory.

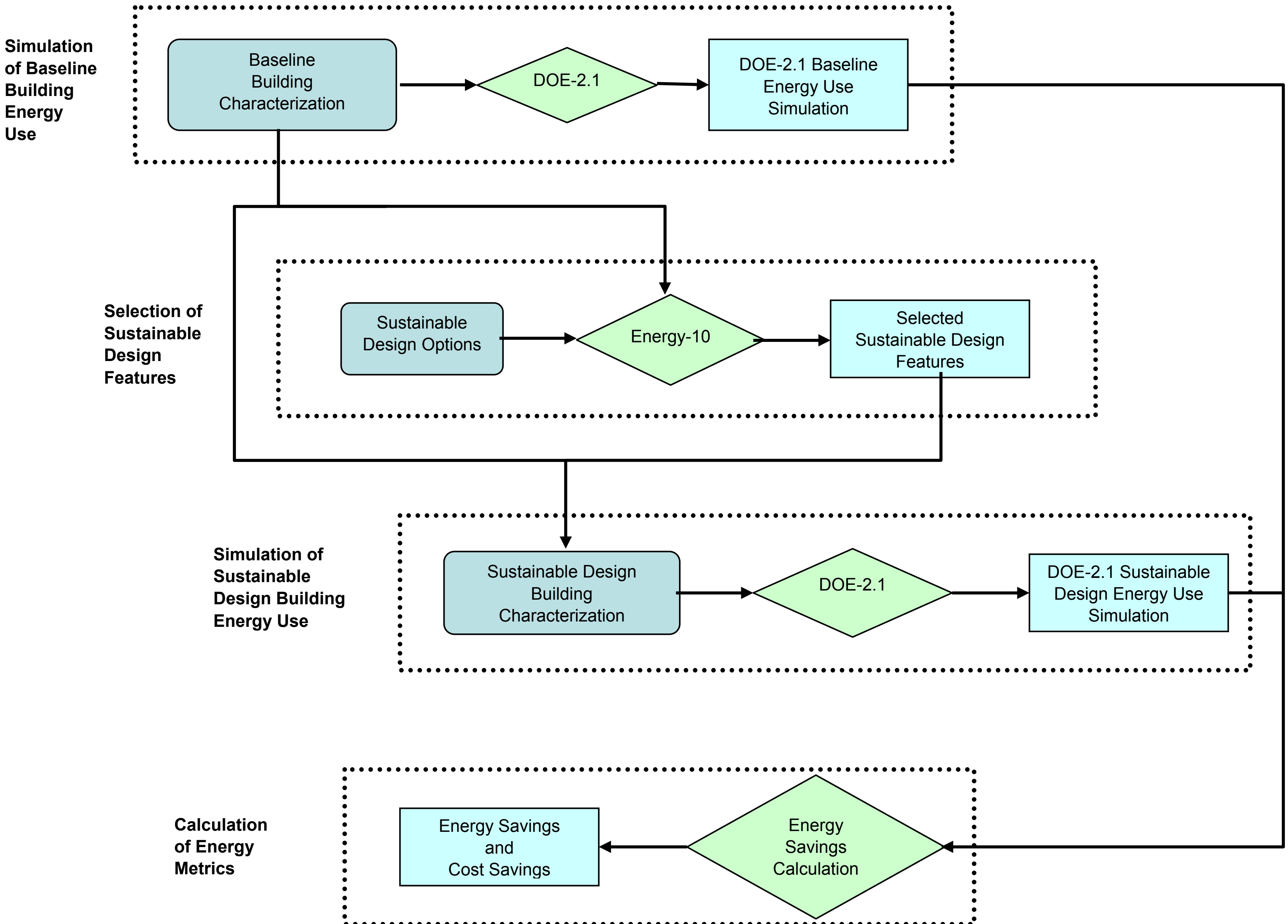

Figure B-1. Energy Simulation Flow Diagram

using simple inputs such as the square feet of the building and subareas and the generic type of structural system. The parametric tool was the Commercial Construction Knowledgebase module within "Timberline Precision Estimating – Extended Edition, Version 6.2."[2] Timberline uses RS Means cost data and adjusts costs to Baltimore, Maryland. The Timberline parametric modules allow some specific inputs for a building such as specifying gas or electric heat. This study specified some of those inputs to approximate the natural gas heating for the base-case building but otherwise relied on the modules' assumptions.

B.1.3 Building Occupancy Type and Size

The study focused on an office-building model. According to the U.S. General Services Administration (GSA), offices are the second largest square-footage category (after housing) and the largest building cost category. The study selected a building size of 20,000 ft^2 because the average size of the office buildings in GSA's inventory is 20,979 ft^2.

B.1.4 Building Location

The study selected Baltimore, Maryland, as the location for the DOE-2.1e and construction cost estimating because it represented a large city with a substantial Federal construction market and a moderate East Coast climate. Because one purpose of this study is to help guide new Federal construction projects, the study reviewed FY 2002 capital appropriations and found that roughly two-thirds of the appropriations were slated for states in the southern half of the continental United States. The appropriations for California appeared to be the highest of any individual state. However, when grouping states into informal regional climate zones, the states in the "moderate eastern climate" zone had significantly more appropriations than California. The selection of an appropriate average climate was also based on Pacific Northwest National Laboratory's (PNNL's) experience gained through developing ASHRAE 90.1-1999 and Federal Energy Code (10 CFR 434) standards.

B.1.5 Energy Rates

The study used energy cost rates for Baltimore, Maryland, as shown in Table B-1. The rates were developed from the local utility, Baltimore Gas and Electric Company (BGE). Baltimore is a deregulated utility market and BGE's rate structure has many options to select from despite a few frozen tariffs. Apparently, GSA has a contract with BGE with very different schedules – see http://hydra.gsa.gov/pbs/xu/areawides/word/bgemod.doc. For simplicity, this study developed an average or blended rate based on the information provided through BGE's website (the current link is http://www.bge.com/cmp/CDA/section/0,1668,603,00.html). This study used $0.077 per kilowatt-hour (kWh) and $0.692 per therm based on review of BGE rate schedules.

Table B-1. Energy Rates for the Base-Case Building

	Rate
Natural gas ($/therm)	$0.692
Electricity ($/kWh)	$0.077

[2] http://www.timberline.com/products/estimating/commercial_construction_knowledgebase.htm.

Derivation of Blended Electricity Rate

Commercial buildings such as the one used in the study's base-case building are likely to be on a general service or a small general service rate schedule. Neither schedule is a typical demand schedule. The general service schedule has two complex options for the energy demand charge averaging summer and non-summer costs. The small general service schedule does not have a standard demand rate but uses peak and offpeak rates. The base simple general service schedule option would be as follows:

Base rate	$11.50/month
Energy charge	
October through May	$0.03749/kWh
June through Sept.	$0.05383/kWh
Transmission charge	$0.00298/kWh
Delivery service charge	$0.02250/kWh
Competitive transmission charge	$0.00576/kWh

The above rates can be simplified to the following schedule for the study's base-case building:

Base rate	$11.50/month
Energy charge	
October through May	$0.06873/kWh
June through Sept.	$0.08507/kWh

Derivation of Blended Gas Rate

The general service gas schedules are located at http://www.bge.com/CDA/Files/Bsch_c.doc; however, this schedule appears to cover delivery cost but not the energy cost:

Customer charge	$27.00 /month
Delivery price	
First 10,000 therms	$0.1724/therm
All remaining therms	$0.0936/therm

BGE also charges separately for automated/daily metering. A complete rate was obtained by BGE customer service, who reported that costs varied between the three major suppliers in the area and from year to year. However, the average costs based on the last two years available are shown in Table B-2.

Table B-2. Average BGE Rate (based on the last two years)

			$/Therm
January	$0.570	July	$0.502
February	$0.597	August	$0.458
March	$0.504	September	$0.461
April	$0.517	October	$0.498
May	$0.495	November	$0.476
June	$0.500	December	$0.562

B.1.6 Base-Case Building Design Assumptions

Table B-3 summarizes the key input assumptions used for the base-case building design in the DOE-2.1E models.

Table B-3. Base-Case Assumptions Used in the DOE-2.1E Models

	Base-Case Assumptions
General	
Building type	Office
Location	Baltimore, Maryland
Gross area	20,164 ft^2
Operating hours	8am - 5pm Monday-Friday
Utility rates	
Electric energy rate	Base rate: $11.50/month
	Energy charge: $0.077/kWh
Natural gas price ($/therm)	Base rate: $27.0/month
	Energy charge: $0.692/therm
Architectural features	
Configuration/shape	
Aspect ratio	2:1
Perimeter zone depth	15 ft
Number of floors	2
Window area	20% window-to-wall ratio
Floor-to-ceiling height	9 ft
Floor-to-floor height	13 ft
Exterior walls	
Wall type	4" Face brick façade on 16" on-center metal framing
Opaque wall U-value	0.124
Wall insulation	R-13 cavity insulation
Roof	
Roof type	Builtup roofing with concrete deck
Solar absorptance	0.7 (medium dark)
Roof U-value	0.063 Btu/hr-ft^2-°F
Roof insulation	R-15 continuous insulation
Floor structure	
Floor type	Concrete
Floor insulation	R-5.4 perimeter insulation*
Fenestration/windows	
Window type	Aluminum frames with thermal beaks and double panes
Total U-value	0.57 Btu/hr-ft^2-°F
Shading coefficient	0.45

	Base-Case Assumptions
Visual transmittance	0.52
Window shading/overhangs	None
Building internal loads	
Occupancy	
Number of occupants	96
Occupancy schedule	8am - 5pm Monday-Friday
Lighting	
Fixture type	T-8 with electronic ballasts
Peak lighting power density	1.38 watts/ft² (net building wattage from ASHRAE's space by space analysis)
Lighting schedule	7am - 6pm Monday-Friday
Occupancy sensors	None
Daylighting	None
Office equipment	
Equipment schedule	7am - 6pm Monday-Friday
Peak load density	0.72 watts /ft²
HVAC system	
HVAC system type	Package rooftop unit; constant-air-volume with gas furnace
Number of HVAC units	Five units to serve five HVAC thermal zones
Space temperature setpoint	75°F coling/70°F heating
Space setback/setup	80°F cooling/65°F heating
Cooling equipment efficiency	10.1 EER
Outside air supply	20 cubic feet/minute (cfm) per person, 17% of supply air cfm
Heating furnace efficiency	80%
Ventilation control mode	Constant during occupied periods, cycle during unoccupied periods
Economizer	None
Design supply air	Minimum 0.5 cfm/ft²
Air-to-air energy recovery ventilation	None
Fan total static pressure	2.0 in. total, 1.0 in. related to ductwork system
Fan schedule	6am - 6pm Monday-Friday with night cycle on/off
Fan motor efficiency	85%
Fan efficiency	65%
Service/domestic/potable water heating	
Hot water fuel type	Natural gas
Thermal efficiency	80%
Supply temperature	120
Hot water consumption	0.9 gallons per day/person
* Exceeds ASHRAE 90.1-1999.	

B.2 Selection of Sustainable Design Features

The National Renewable Energy Laboratory (NREL) performed a screening analysis of potential sustainable design options using ENERGY-10, a PC-based software design tool developed by NREL. The rationale for using ENERGY-10 in this study is that with the new lifecycle costing capabilities of Version 1.6, it is quick and easy to search possible solutions and narrow the optimal combination of measures for further analysis with the more detailed DOE-2.1E model (see section B.5 for a brief discussion of the differences between ENERGY-10 and DOE 2.1E). ENERGY-10 was used to initially assess and optimize a number of design options:

- Changes in the installed lighting power density
- Addition of daylighting controls
- Changes in building aspect ratio
- Skylighting in the building core
- Changes in fenestration area by orientation for daylighting, passive solar heating, and cooling load avoidance
- Changes in building insulation levels.

The NREL screening analysis, documented in this section, was used to characterize a suite of measures that maximizes energy savings and reduces the lifecycle cost of the sustainable building. However, many of the details of the implementation of the sustainable design options differ between their characterization in the NREL screening analysis and the final DOE-2.1E simulation. This section documents the screening analysis, while Section B.4 documents the final sustainable building simulation.

B.2.1 Aspect Ratio

One feature varied in the analysis was the aspect ratio[3] of the building (see Figures B-2 and B-3). For a building of 20,000 ft^2 and two stories, an aspect ratio of less than 6 requires a core zone, whereas an aspect ratio from 6 to 12 could be a double-loaded corridor with no core zone. For the base case, a window-to-wall-area ratio of 0.20 was maintained for all four sides. For the energy-efficient case (designated the "EE" case in the figures), the south window-to-wall-area ratio was as follows: south, 0.38; east, 0.07; west, 0.05; and north, 0.11.

Energy use was minimized by an aspect ratio of 1.5 for both the base and sustainable cases.[4] However, for the sustainable design, the benefits of passive solar heating and daylighting compensated for the increased surface area, and energy use increased only slightly with increasing aspect ratio. However, increasing aspect ratio increased first costs substantially because of the additional materials to accommodate the increased surface area for both the base and sustainable design cases.

[3] The ratio of the longer side of the building to the shorter side.

[4] In DOE-2.1e aspect ratio was 2.0 in both the base and sustainable cases. This may have resulted in a slightly higher energy use and capital cost than the ENERGY-10 simulation, but differences were not deemed significant enough to warrant changing the model setup.

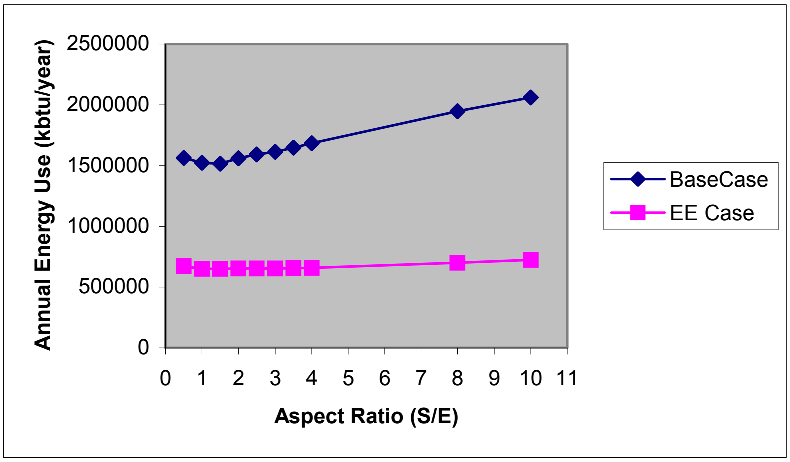

Figure B-2. Annual Energy Use (kBtu/yr) versus Aspect Ratio (south/east)

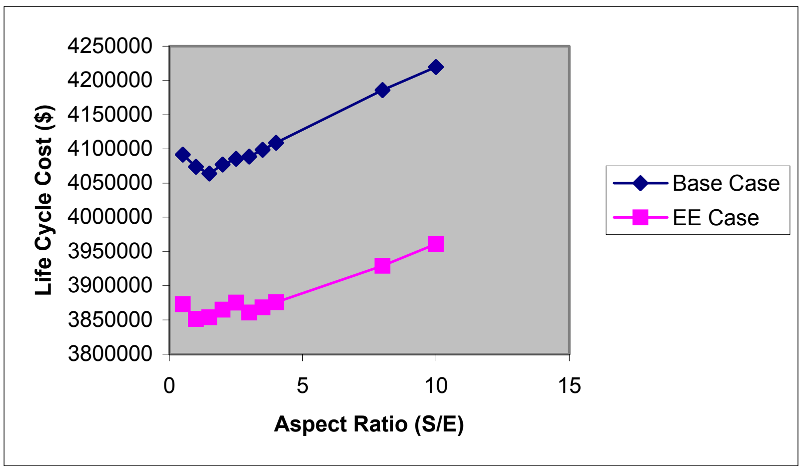

Figure B-3. Lifecycle Cost ($) versus Aspect Ratio (south/east)

B.2.2 Energy Conservation Measures

Eight energy conservation measures (ECMs) were selected to define the sustainable building: daylighting, improved windows, improved lighting efficiency, window shading, improved insulation, passive solar heating, economizer cycle, and high-efficiency equipment. Each measure and its cost are briefly described below.

ECM 1 – Daylighting

Ten lighting zones were set up, one facing each direction (i.e., east , south, west, and north) on each floor, a core zone on the top floor with 12 skylights, and a 4592 ft^2 core zone on the first floor with no daylighting. Continuous dimming controls maintain a 50-foot-candle lighting level. The cost of this measure was $188/ lighting zone for dimming sensor and controls and $0.75/ ft^2 of floor space to cover the cost of upgrading to dimming ballasts. Therefore, the total cost of daylighting controls was $13,371.

Window dimensions were optimized and costed in the passive solar heating ECM (described below), including the effects of daylight savings. The 4592-ft^2 core zone on the second floor is daylit only by skylights. The ratio of skylight area to zone roof area was varied from 0.02 to 0.08, and annual energy use was minimized by an area ratio of 0.06. The cost of skylights was estimated at $90/ft^2, which is significantly more expensive than wall windows. Figures B-4 and B-5 show the annual energy use and lifecycle costs, respectively, as functions of skylight to zone roof area.

ECM 2 – Improved Windows

Double-pane windows with U=0.67 Btu/hr-ft^2-°F were replaced with low-emissivity windows with U=0.31 Btu/hr-ft^2-°F; the solar heat gain coefficient remains at 0.39 for both, but the premium

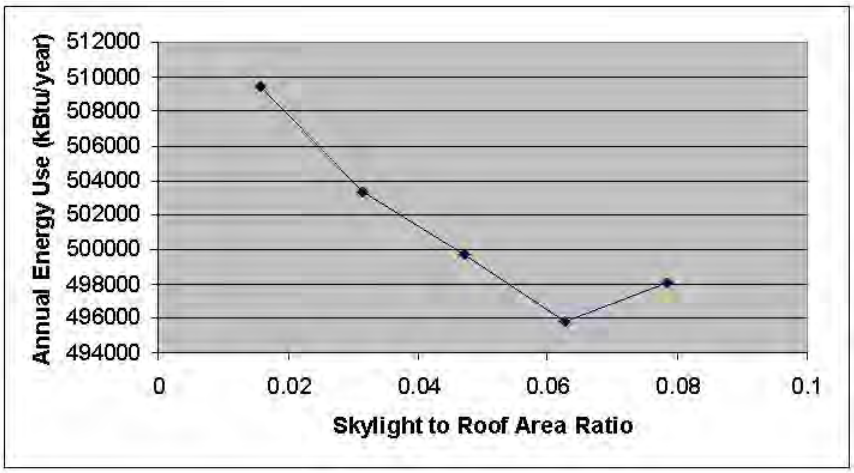

Figure B-4. Annual Energy Use (kBtu/yr) as a Function of Skylight to Zone Roof Area Ratio

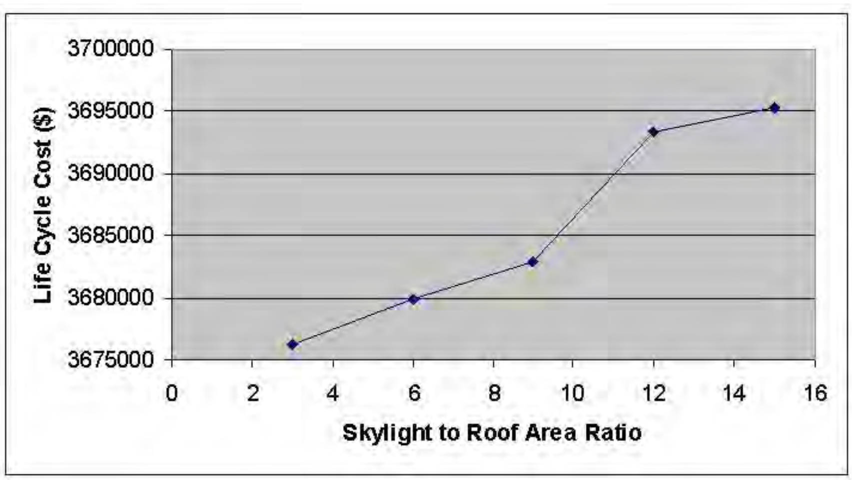

Figure B-5. Lifecycle Cost ($) as a Function of Skylight-to-Zone-Roof-Area Ratio

glazing uses a selective surface with visible transmittance of 0.7. The cost of the premium glazing was $25 ($22 to $28/ft^2) for item 08810 3004000 in RS Means (2002) (super-efficient glazing, triple-glazed with low-e glass, argon filled U=0.26). The cost of standard glass was $22.50 for item 4600400 in RS Means (2002) (3/16 float, 5/8 thick unit, U=0.56) for a $2.50/ft^2 difference or $1.22/ft^2/R-value. Table B-4 lists the results of the glazing improvement.

Table B-4. Results of Glazing Improvement

	Base Case	Premium Glazing
Window construction	Buscase, U=0.67	4060 low-e al/b, U=0.31,etc.
Window total gross area (ft^2)	2,208	2,208
Windows (north/east/south/west:roof)	23/23/23/23:0	23/23/23/23:0
Glazing name	Buscase, U=0.56	Double low-e selective, U=0.26
Energy use (kBtu)	904,917	820,385
Energy cost ($)	16,058	15,633
Construction costs	3,146,828	3,149,669
Lifecycle cost	3,815,530	3,805,379

ECM 3 – Improved Lighting Efficiency

The lighting power density was reduced from 1.38 to 1.0 W/ft^2 by architectural design of the lighting system and premium efficiency equipment. The cost was estimated at $0.36/ft^2 or $7259.

ECM 4 – Window Shading

Overhangs provide shade over the south-facing windows. The cost was estimated at $12.37/ft of overhang projection per linear foot of shaded window. Only windows facing east, south, and west were supplied with overhangs for a linear window length of 360 ft. Overhang projection was varied in the model from 0 to 4 ft, with a 3-ft projection minimizing annual energy use. The cost of the 3-ft projection was $13,359. Figures B-6 and B-7 show the annual energy use and lifecycle costs, respectively, as a function of overhang projection.

ECM 5 – Improved Insulation

Six wall cross-sections were considered to achieve different R-values: R-9, R-18, R-22, R-36, and R-50 and R-1000 (R-1000 was also considered just to provide a limiting case of the importance of insulation). While R-36 provides the lowest lifecycle cost, it is only slightly lower than R-18, so R-18 was adopted. Figure B-8 shows the net present value as a function of wall U-value (the inverse of the R-value).

The overall loss coefficient of the envelope was reduced from 3276 to 1556 Btu/hr-°F at a total cost of $18,868. (Upgrading to 6-in. steel frame walls with polyisocyanurate insulation added $0.05/unit R-value/ft^2 of wall area or $3943 for wall insulation; adding foam insulation to reduce the slab perimeter F-value from 0.35 to 0.20 Btu/hrft^2-°F cost $5/ft of perimeter or $8283 for foundation insulation; improving roof insulation added $0.03/unit R-value/ft^2 of roof area totaling $6505 for roof insulation; and adding premium doors cost $137.)

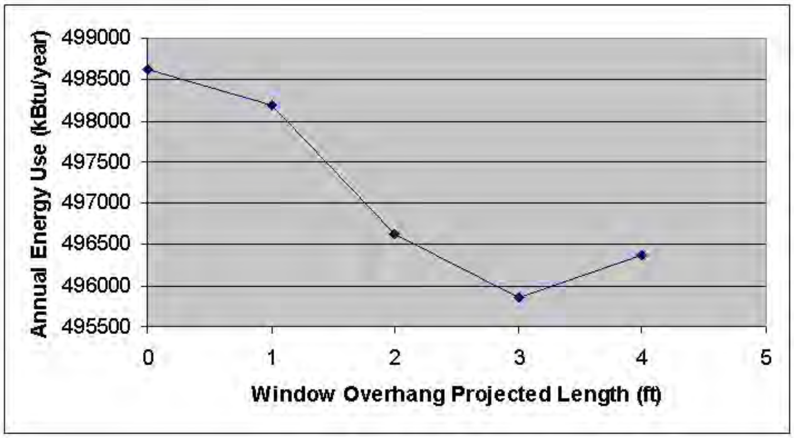

Figure B-6. Annual Energy Use (kBtu/yr) as a Function of Overhang Projection (ft)

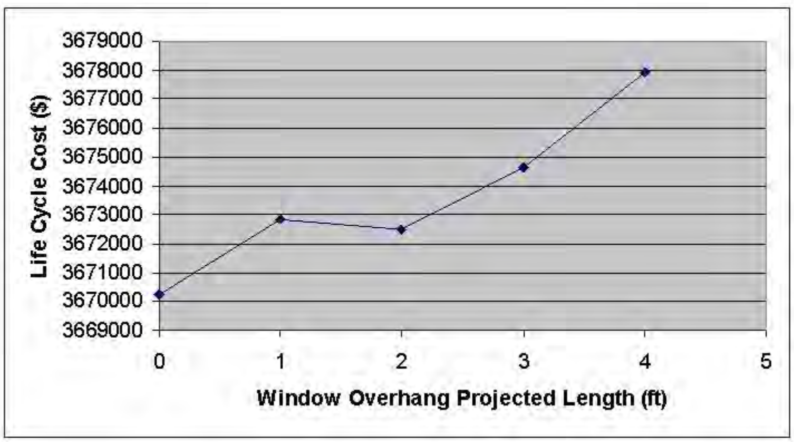

Figure B-7. Lifecycle Cost ($) as a Function of Overhang Projection (ft)

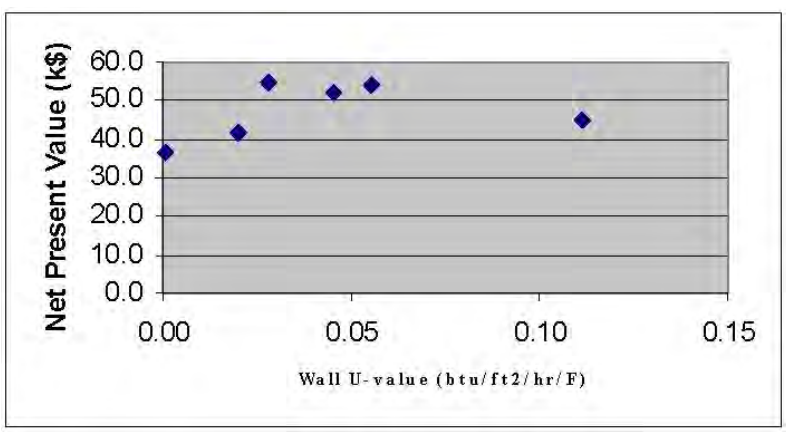

Figure B-8. Net Present Value (k$) as a Function of Wall U-Value

ECM 6 – Passive Solar Heating

The amount of glazing on the east, west, north, and south walls was varied to minimize annual energy use. The passive solar heating measure was implemented by changing from an even distribution of windows on all sides (20% window-to-wall-area ratio) to the following distribution:

- 0.15 on the north
- 0.10 on the east
- 0.10 on the west
- 0.30 on the south.

The total window area in the walls decreased from 2208 ft^2 to 2064 ft^2 (not including the 12 skylights in the daylighting measure). The cost was $25/$ft^2$ of window area for a total cost savings of $3600 over the base case. Figures B-9 through B-16 show the annual energy use and lifecycle costs as a function of the window-to-wall-area ratios for east, west, south, and north windows, respectively.

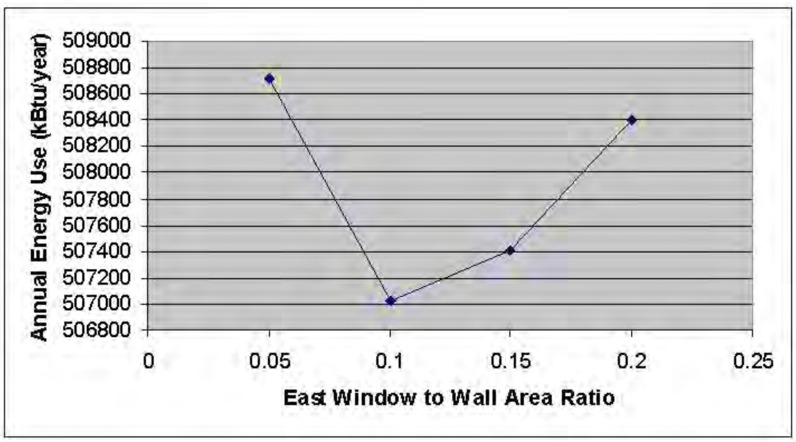

Figure B-9. Annual Energy Use (kBtu) as a Function of East Window-to-Wall-Area Ratio

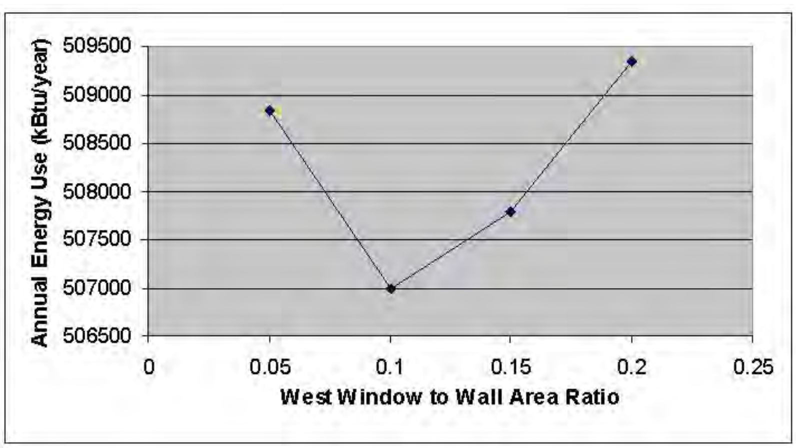

Figure B-10. Annual Energy Use (kBtu) as a Function of West Window-to-Wall-Area Ratio

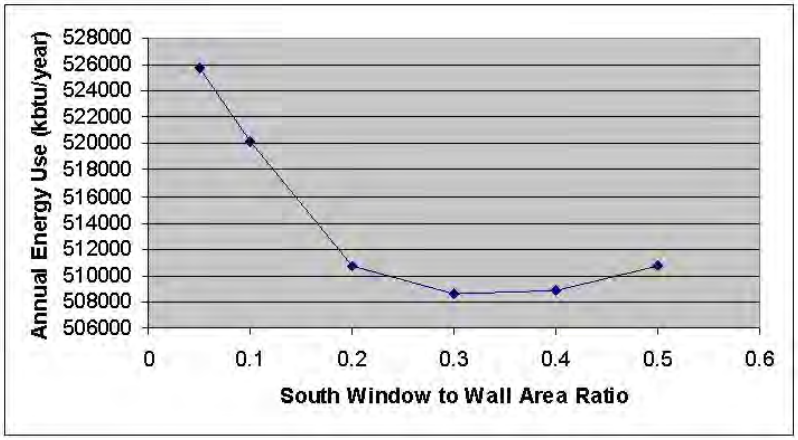

Figure B-11. Annual Energy Use (kBtu) as a Function of South Window-to-Wall-Area Ratio

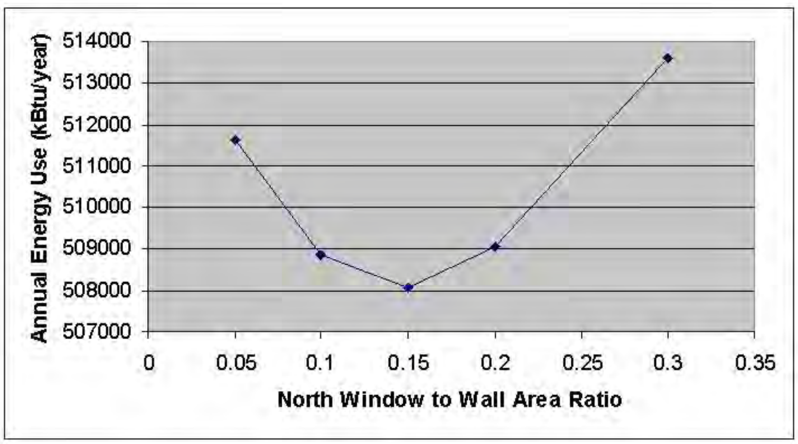

Figure B-12. Annual Energy Use (kBtu) as a Function of North Window-to-Wall-Area Ratio

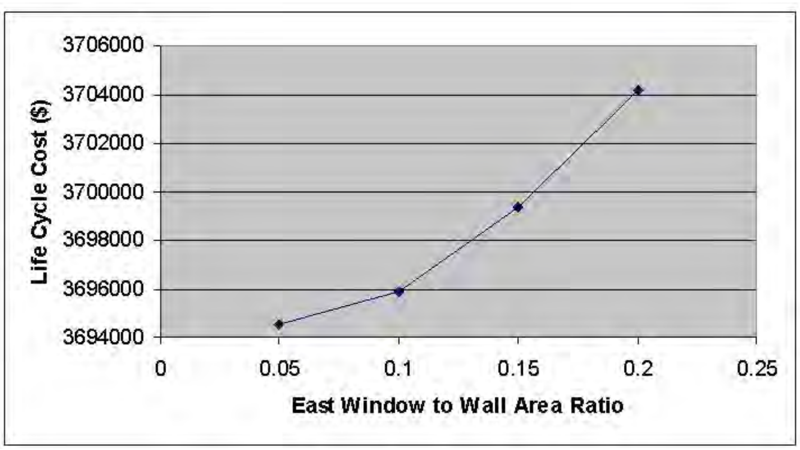

Figure B-13. Lifecycle Cost ($) as a Function of East Window-to-Wall-Area Ratio

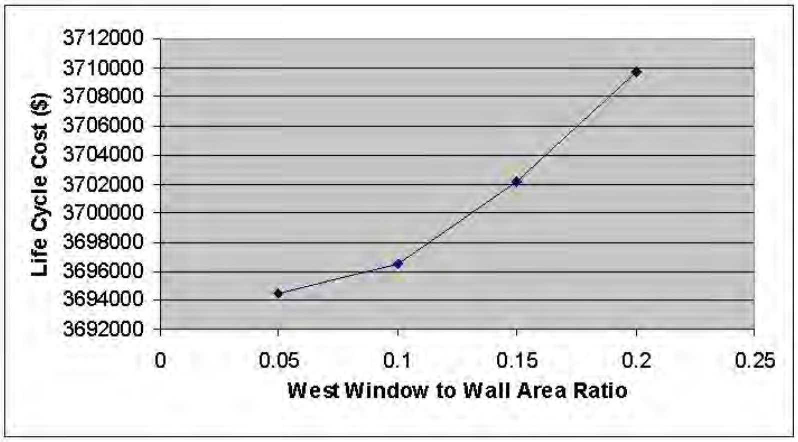

Figure B-14. Lifecycle Cost ($) as a Function of West Window-to-Wall-Area Ratio

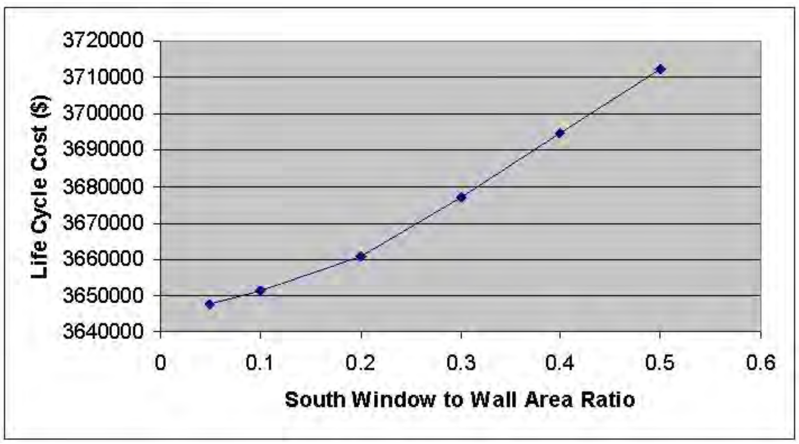

Figure B-15. Lifecycle Cost ($) as a Function of South Window-to-Wall-Area Ratio

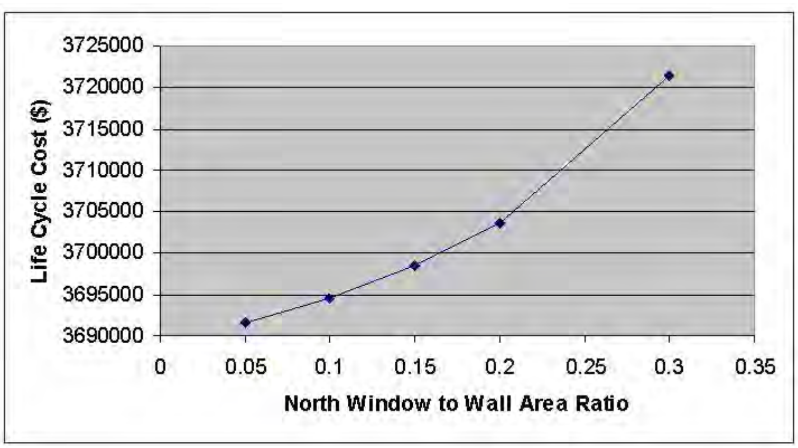

Figure B-16. Lifecycle Cost ($) as a Function of North Window-to-Wall-Area Ratio

ECM 7 – Economizer Cycle

An economizer was added with a fixed dry bulb temperature of 60°F. The cost was \$0.25/ft^2 of floor area for a total cost of \$5041.

ECM 8 – High-Efficiency Equipment

HVAC efficiency was improved by using larger ducts and more efficient equipment. Heating efficiency was raised from 80% to 90% at a cost of \$1.00/unit of heating capacity in kBtu/hr per unit increase in efficiency. Cooling efficiency was raised from an EER of 10.1 to 13.0 at a cost of \$5.00/unit of cooling capacity in kBtu/hr per unit of improvement in EER. The total cost of the mechanical equipment upgrades was therefore estimated to be \$7006.

B.3 Simulation of the Energy Use of the Sustainable Building

The sustainable building was characterized by incorporating the information developed in the NREL screening analysis with the base-case building characterization. Figure B-17 lists the features incorporated in the sustainable building, and Table B-5 shows the sustainable building characterization.

The study developed construction and replacement cost estimates for the evaluated building energy features from several sources, including vendors and facility engineering staff (through personal communication), vendor websites, RS Means construction cost estimating books, and case studies and reports. Table B-6 summarizes the estimates and sources. The estimates are shown as the net incremental cost change (increase or decrease) to the base-case construction cost.

B.4 Results of the Energy Simulations

B.4.1 Energy Use and Energy Cost Estimates

Tables B-7 and B-8 show the energy use and energy cost by end use for both the base-case and the sustainable buildings. The tables show energy use and cost with and without plug loads. Although the model estimated energy consumption for plug loads and other miscellaneous office equipment, these were not included in the analysis of the percent energy reductions that could be achieved using various energy efficiency technologies. This is consistent with the practice within the Leadership in Energy and Environmental Design (LEED™) Rating System.

B.4.2 Lifecycle Cost Calculations

This study estimated the lifecycle cost or present value of the initial construction costs, the outyear replacement costs, and the annual energy costs over 25 years. Most replacement costs were based on the service life values in Table 27.3 in Marshall and Petersen (1995). This study did not evaluate the costs of annual recurring maintenance, the cost of nonrecurring or irregular repairs and maintenance, or the cost impacts on the environment and occupants' productivity.

The lifecycle cost tool was an Excel spreadsheet workbook titled, "User-Friendly Building Life-Cycle Cost Analysis" (M.S. Addison and Associates 2002). The developers say the workbook is compliant with National Institute of Standards and Technology Handbook lifecycle costing procedures and offer the workbook free of charge at http://www.doe2.com/. The study used the following key inputs for the lifecycle cost workbook:

• DOE/FEMP fiscal year	2002
• Real discount rate for this analysis	3.2%
• Number of analysis years	25
• DOE fuel price escalation region	3 (south)
• Analysis sector	2 (commercial).

Table B-9 shows the lifecycle cost calculations for the base-case and the sustainable buildings.

Lighting Measures

- **Increased daylighting.** Skylights were added, increasing daylight to the top floor.
- **Reduced lighting intensity.** Lighting power densities recommended by the Illuminating Engineering Society of North America and ASHRAE, as a proposed addenda to the 90.1 standard, were adopted. The lighting level was reduced from 40 to 35 footcandles in the office area, with some increase in task lighting.
- **Perimeter daylighting controls with dimmers.** Daylight sensors (six per floor) control stepped ballast controls so that electric lighting is dimmed when sufficient daylight exists. In the base case, no dimming of electric lighting occurs.

Envelope Measures

- **Window distribution.** The square footage of the windows was redistributed to optimize solar gain with heating and cooling costs. The optimized window-to-wall ratio is 15% window for the north wall, 10% window for the east and west walls, and 30% window for the south wall. The base-case ratio is 20% for all walls.
- **Additional wall insulation.** On the outside face of the exterior wall framing, R-10 rigid insulation was added compared with only R-13 batt insulation in the base-case walls. The resulting insulation in the sustainable building was R-23.
- **Additional roof insulation.** The R-15 rigid insulation was increased to R-20.
- **White roof.** A white roof finish material with low solar radiation absorptance of 0.30 was used compared with the base case's absorptance of 0.70.
- **Highly energy-efficient windows.** The sustainable option balances window performance with the low lighting levels and the use of daylighting controls. The result is a cost-optimized window with a U-factor of 0.31 and a shading coefficient of 0.39.

Mechanical Systems

- **High-efficiency air conditioner.** The air conditioning unit has an energy-efficiency ratio of 13 compared with 10 for the base case.
- **High-efficiency water heater.** A 90% thermal efficiency condensing water heater was used compared with a commercial gas water heater with 80% thermal efficiency for the base case.
- **Low-pressure ducts.** The fan external static pressure was reduced from 1.0 inch water column to 0.5 inch water column by enlarging the duct sizes.
- **Economizers.** An integrated economizer, including an outside air enthalpy sensor with a high-limit enthalpy setpoint, was used; the setpoint was set at 25 Btu/lb in conjunction with a dry bulb temperature high limit of 74°F.

Figure B-17. Features Included in the Sustainable Building

Table B-5. Characterization of Sustainable Building (includes base-case building comparison)

		Sustainable Building
General		
Building type	Office	Same as in base case
Location	Baltimore, Maryland	Same as in base case
Gross area	20,164 Ft^2	Same as in base case
Operation hours	8am - 5pm Monday-Friday	Same as in base case
Utility Rates		
Electric energy rate	Base rate: $11.50/month	Same as in base case
	Energy charge: $0.077/kWh	Same as in base case
Natural gas price ($/therm)	Base rate: $27.0/month	Same as in base case
	Energy charge: $0.692/therm	Same as in base case
Architectural features		
Configuration/shape		
Aspect ratio	2:1	Same as in base case
Perimeter zone depth	15 ft	Same as in base case
Number of floors	2	Same as in base case
Window area	20% window-to-wall ratio	Redistribute windows to optimize solar gain: north 15%, south 30%, and east and west 10%. Net overall: 18%.
Floor-to-ceiling height	9 ft	Same as in base case
Floor-to-floor height	13 ft	Same as in base case
Exterior walls		
Wall type	4-in. face brick façade on 16-in. on-center metal framing	See next item
Opaque wall U-value	0.124	0.055
Wall insulation	R-13 cavity insulation	Add R-10 rigid foam insulation under brick façade
Roof		
Roof type	Builtup roofing with concrete deck	See next item
Solar absorptance	0.7 (medium dark)	0.3 (white roof)

		Sustainable Building
Roof U-value	0.063	0.048
Roof insulation	R-15 continuous insulation	R-20 continuous insulation
Floor structure		
Floor type	Concrete	Same as in base case
Floor insulation	R-5.4 perimeter insulation*	Same as in base case
Fenestration/windows		
Window type	Aluminum frames with thermal breaks and double panes	See next item
Total U-value	0.57	0.31
Shading coefficient	0.45	0.39
Visual transmittance	0.52	0.70
Window shading/overhangs	None	*Overhang was considered but not included because overhangs made little impact on energy efficiency and the construction cost was substantial.
Building internal loads		
Occupancy		
Number of occupancy	96	Same as in base case
Occupancy schedule	8am - 5pm Monday-Friday	Same as in base case
Lighting		
Fixture type	T-8 with electronic ballasts	Same as in base case
Peak lighting power density	1.38 watts/ft^2 (net building wattage from ASHRAE's space by space analysis)	1.0 watts/ft^2. The density was recommended by the Illuminating Engineering Society of North America and ASHRAE as a proposed addenda to ASHRAE's 90.1 standard. For this building, the level was reduced from 40 to 35 foot candles in the office area.
Lighting schedule	7am – 6pm Monday-Friday	Same as in base case
Occupancy sensors	None	Same as in base case
Daylighting	None	Light sensors and dimmable fixtures the perimeter zones (15 feet in from the window walls). Skylights in second floor core with light sensors and dimmable fixtures.
Office equipment		

		Sustainable Building
Equipment schedule	7am – 6pm Monday-Friday	Same as in base case
Peak load density	0.72 watts/ft^2	Same as in base case
HVAC system		
HVAC system type	Package rooftop constant air volume with gas furnace	Same as in base case
Number of HVAC units	Five units to serve five HVAC thermal zones	Same as in base case
Space temperature setpoint	75°F cooling/70°F heating	Same as in base case
Space setback/setup	80°F cooling/65°F heating	Same as in base case
Cooling equipment efficiency	10.1 EER	13.0 EER
Outside air supply	20 cfm/person, 17% of supply air cfm	Same as in base case
Heating furnace efficiency	80%	Same as in base case
Ventilation control mode	Constant during occupied periods, cycle during unoccupied periods	See next item
Economizer	None	Economizer in each rooftop unit with outside air enthalpy-based controls
Design supply air	Minimum 0.5 cfm/ft^2	Same as in base case
Air-to-air energy recovery ventilation	None	Same as in base case
Fan total static pressure	2.0 in. total, 1.0 in. related to ductwork system	Increase duct size to reduced static pressure to 1.5 inches total (0.5 inches related to ductwork system).
Fan schedule	6am - 6pm Monday-Friday with night cycle on/off	Same as in base case
Fan motor efficiency	85%	Same as in base case
Fan efficiency	65%	Same as in base case
Service/domestic/potable water heating		
Hot water fuel type	Natural gas	Same as in base case
Thermal efficiency	80%	90%
Supply temperature	120	Same as in base case
Hot water consumption	0.9 gallons per minute/person	Same as in base case
* Exceeds ASHRAE 90.1-1999.		

Table B-6. Costs of Technology Options and Data Sources

Alternate Feature or Technology Option	Construction Cost Impact on Base Case	Basis and Source of Cost	Service Life of Alternate
Lighting			
Reduce lighting power density – Level 1: Reduce from 1.38 watts/ft² to 1.0 watts/ft² (from 40 to 35 foot candles)	-$16,970	Based on the watts/ft² (1.0 watt) and the cost/ft² ($2.32) needed to meet the current Illuminating Engineering Society of North America handbooks lighting levels for the space types in the office building design (office, lobby, corridor/support areas, and kitchen) with T-8 fixtures, electronic ballasts, and compact fluorescent lamps). The fixture choices remain the same as in ASHRAE's 90.1-1999 baseline.	25 yr; assumes light replacement costs are the same even though lower light levels reduce the number of fixtures and lamps that need to be replaced – and therefore reduces costs – over the life of the building.
Add perimeter daylighting with dimming control	$11,246	Based on $0.88/ft² for daylighting controls and fully dimming ballasts for all office space in a 15-ft depth from the building perimeter on both floors of the building. The range of cost per ft² was $0.23/ft² to $1.88/ft². One daylight sensor/controller was assumed per 600 ft² of perimeter floor space. Cost data for fully dimming ballasts were based on available costs in the Industrial Supply Lighting Catalog (W.W. Grainger 2000). Controller cost data with installation based on 2001 Means Electrical Cost Data.	15 yr
Add skylights and daylighting controls to center core of building	$18,219	18 skylights, fixed double-glazed, 44 in. x 46 in., $550 each (RS Means BCCD 08600-100-0130), effectively $39.13/ft². Eighteen light wells built up from suspended ceiling t-bar components. Dimmable controls and fixtures at $1.15/ft² of skylit core floor space; $/ft² rate developed from manufacturers' data indicating a range of $0.75 to $0.88/ft²; plus 40% for labor.	Controls: 15 yr Skylights: 25 yr
Mechanical			
Add high-efficiency air conditioning (increase EER from 10 to 13)	$5,686	Base-case costs developed from distributors' purchase cost data collected during analysis of unitary air conditioning equipment for DOE's EPAct standards program, 2000-2002. Baseline system cost would then be $475/ton of cooling and the alternate would be $510/ton for an incremental cost of $40/EER/ton. A 25% distributor-to-contractor cost markup was assumed. The sustainable design option (EER 13) was taken from DOE's Unitary Air Conditioner Technology Procurement website at http://www.pnl.gov/uac/products.stm.	25 yr for both the base case and sustainable building

Alternate Feature or Technology Option	Construction Cost Impact on Base Case	Basis and Source of Cost	Service Life of Alternate
Add economizer with enthalpy-based controls	$2,700	Based on $540/rooftop air-handling units (5 units total) based on materials from multiple manufacturers.	15 yr; assumes controls are the weak point
Enlarge duct sizes to reduce static air pressure at fans and therefore reduce fan and motor sizes	$7,000	Based on ductwork at $1200/ton for baseline pressure duct design (0.1 in. H_2O/100-ft-length pressure drop) and $1400/ton for a low-pressure design (0.05 in./100-ft pressure drop). Assumes 120 lb of sheet metal per ton of air conditioning and $6.40/lb for the duct plus insulation cost. Cost data from RS Means Building Construction Cost Data.	25 yr [Note: although the expected lifetime is 30 years, the analysis has a 25-year time-frame, so lifetimes past 25 years are not considered.]
Envelope			
Add 1-in. (R-10) rigid foam board insulation behind brick façade	$2,946	Isocyanurate, 4 x 8 sheets, foil-faced, both sides. 1.5-in.-thick, R-10.8. RS Means 072-100-116-1650: $0.88.	25 yr for both the base case and sustainable building
Decrease total U-value from 0.57 to 0.31; decrease shading coefficient from 0.45 to 0.39; and increase visual transmittance from 0.52 to 0.70	$5,538	Cost of premium glazing is $25 ($22 to $28/ft^2) for item 08810 3004000 in RS Means (super-efficient glazing, triple-glazed with low-e glass, argon filled U=.26). Standard glass cost is $22.50 for item 4600400 in RS Means (3/16 float, 5/8 thick unit, U=.56) for a $2.50/ft^2 difference.	25 yr for both the base case and sustainable building
Reallocate window distribution to optimize solar gains	-$3,457	Based on $37.24/ft^2 for windows and $18.52 for wall. Baseline window-to-wall ratio was 20% and the sustainable design case nets 18%. Window cost decreased $6875. Wall cost increased $3418.	25 yr
Increase roof insulation from R-10 to R-20	$1,916	Based on difference in Means construction costs between baseline of 3-in. expanded polystyrene (R-11.49, $0.82/ft^2) and 3-in. polyisocyanurate (R-21.74, $1.01/ft^2).	25 yr for both the base case and sustainable building
Replace roofing with a white roof system	$1,553	Based on a 10% extra cost ($0.15/ft^2) for white over baseline roofing at $1.54/ft^2. Unit costs derived from RS Means Building Construction Cost Data (1999), line numbers 075-302. Manufacturers' information indicates the additional cost may be higher, possibly a multiple of 2.	25 yr for both the base case and sustainable building
Other			
Replace gas-fired service hot water heater (80% efficiency) with higher-efficiency unit (90% efficiency)	$1,200	Based on review of cost information from multiple manufacturers/ vendors and web-based reports.	25 yr for both the base case and sustainable building

Table B-7. Simulated Energy Use by End Use for the Base-Case and Sustainable Buildings

End Use	Fuel	Units	Base-Case Building	Sustainable Building	% Change
Lighting	Electricity	kWh	79,314	41,518	-47.7%
Space cooling	Electricity	kWh	23,440	17,082	-27.1%
Space heat	Natural gas	Therms	2,606	1,854	-28.9%
Other	All	Million Btu	118	92	-22.4%
Fans	Electricity	kWh	15,207	10,401	-31.6%
Pumps and misc.	Electricity	kWh	674	879	30.4%
Hot water	Natural gas	Therms	642	534	-16.8%
Total	All	Million Btu	730	477	-34.6%

Table B-8. Simulated Annual Energy Costs by End Use for the Base-Case and Sustainable Buildings

End Use	Fuel	Units	Base-Case Building	Sustainable Building	% Change
Lighting	Electricity	$/Yr	6,099	3,193	-47.7
Space cooling	Electricity	$/Yr	1,803	1,314	-27.1
Space heat	Natural gas	$/Yr	1,804	1,284	-28.9
Other	All	$/Yr	2,128	1,699	-20.1
Fans	Electricity	$/Yr	1,169	800	-31.6
Pumps and misc.	Electricity	$/Yr	52	68	30.4
Hot water	Natural gas	$/Yr	445	370	-16.8
Base energy charges	All	$/Yr	462	462	0.0
Total	All	$/Yr	11,834	7,489	-36.7

Table B-9. Lifecycle Cost Calculations for the Base-Case and Sustainable Buildings

Cost Element	Units	Base-Case Building	Sustainable Building	Difference (Sustainable Base)	% Difference	Comments
Investment cost						
Total first cost	$	$2,400,000	$2,437,578	$37,578	1.6%	
Present value (investment cost)	$	$2,400,000	$2,449,565	$49,565	2.1%	Present value investment cost differs from first cost in the sustainable building because of replacement costs for lighting controls and economizers, which are assumed to have a 15-year life.
Annual energy costs						
Annual electricity cost	$/Yr	$9,123	$5,374	($3,749)	-41.1%	
Annual natural gas cost	$/Yr	$2,249	$1,653	($595)	-26.5%	
Annual fixed costs	$/Yr	$462	$462	$0	0.0%	Represents fixed energy connection charges.
Total annual energy cost	$/Yr	$11,834	$7,489	($4,345)	-36.7%	
Present value of energy costs						
Present value (electricity cost)	$	$151,985	$89,525	($62,461)	-41.1%	
Present value (natural gas cost)	$	$39,022	$28,690	($10,332)	-26.5%	
Present value (fixed energy costs)	$	Not included in the lifecycle cost	Not included in the lifecycle cost	Not applicable	Not applicable	Fixed charges not included in the lifecycle cost calculation. Because they are not impacted by the sustainable design options, they have no impact on the cost-effectiveness calculations.
Present value (total energy cost)	$	$191,007	$118,214	($72,793)	-38.1%	
Lifecycle cost	$	$2,591,007	$2,567,780	($23,228)	-0.9%	

B.5 ENERGY-10 and DOE-2.1E

While ENERGY-10 was designed for use with small buildings (i.e., 10,000 ft^2 or less in floor area), its ability to quickly assess the energy-use and lifecycle cost impact of design changes was used even with this study's larger, 20,000-ft^2 building. The same features that make ENERGY-10 quick and easy to use also limit its flexibility, and the base-case building in DOE-2.1E and ENERGY-10 exhibited some differences in cooling load and fan power.

The two models handle fundamental building characteristics in significantly different ways, including the limited equipment choices in ENERGY-10 and the fact that ENERGY-10 only models one or two zones. While a single zone may be appropriate for small buildings such as houses and small retail buildings, larger buildings may have substantial variation in thermal loads across the building, requiring some way to provide for individually served thermal zones. In addition, ENERGY-10's feature to automatically set up daylighting zones places the daylight sensor in the center of the zone, which in this case is close to a window, and therefore overestimates daylighting savings.

ENERGY-10 provides for a very simplified user entry using its "autobuild" procedure to create a very basic "shoe box" building model; however, the desire to match the prototype building led the team to specify a building description that closely matched the characteristics of the ASHRAE 90.1-1999 compliant base-case building modeled in DOE-2.1E.

In developing the specific features of the base-case building in ENERGY-10, careful attention was paid to the fundamental building characteristics so that they would be the same in the base-case ENERGY-10 and DOE-2.1E models. Less attention was focused on the final building energy use or EUI (kBtu/ft^2/yr). However, there were limits to how well the fundamental descriptions for infiltration, cooling equipment efficiency, and the presence of a building return air plenum could be matched between the ENERGY-10 and the DOE-2.1E base-case buildings. In the end, the base-case building simulations in the DOE-2.1E and ENERGY-10 models resulted in the buildings having very similar overall site energy consumption (within 1% of each other) and very similar scheduled energy use (lighting and plug and hot water loads total within 2% of each other). However, the ENERGY-10 base-case simulations showed higher cooling and fan energy consumption and lower heating energy use consumption than in the DOE-2.1E simulations. This may be explained by the known differences in implementation discussed above; the remaining difference may be attributable to the different underlying simulation engines. Note that ENERGY-10 calculates very different estimates of cost effectiveness measures for the energy-efficiency options, with an overall return on investment of 11%. The differences remain an area of study.

Table B-10 shows the ENERGY-10 description of the base-case building and of a low-energy version (i.e., sustainable design) of that base-case building. The low-energy building was developed by selecting from among the potential sustainable design options.

Table B-11 shows the results of the ENERGY-10 simulations of the base-case and sustainable buildings. Table B-12 shows the estimated cost impacts of the sustainable design options from ENERGY-10. These cost estimates were used to generate the lifecycle cost analysis used in the screening effort, but these are not the costs used in the final simulation of the sustainable building in DOE-2.1E. See Section B.4 for documentation of the final simulation of the sustainable building.

Table B-10. Summary of Base-Case and Sustainable Buildings

		Sustainable building
Building characteristics		
Weather file	Baltimore	Baltimore
Floor area (ft^2)	20,164	20,164
Surface area (ft^2)	31,240	31,240
Volume (ft^3)	262,132	262,132
Total conduction loss coefficient (Btu/hr-°F)	3,276	1,556
Average U-value (Btu/hr-ft^2-°F)	0.105	0.050
Wall construction	Buscase 6, R=8.9	Steelstud 6 poly, R=18.1
Roof construction	Buscase, R=15.9	Flat, R=38.0
Floor type, insulation	Slab on grade, R_{eff}=67.6	Slab on grade, R_{eff}=118.3
Window construction	Buscase, U=0.67 Btu/hr-ft^2-°F	4,060 low-E aluminum/thermobreak, U=0.31 Btu/hr-ft^2-°F
Window shading	None	3 ft overhangs on east, south, and west windows
Wall total gross area (ft^2)	11,076	11,076
Roof total gross area (ft^2)	10,082	10,082
Ground total gross area (ft^2)	10,082	10,082
Window total gross area (ft^2)	2,208	2,280
Windows (north/east/south/west:roof)	23/23/23/23:0	23/7/46/7:12
Glazing name	Buscase, U=0.56	Double low-E, U=0.26
Operating parameters		
HVAC System	Direct expansion cooling with gas furnace	Direct expansion cooling with gas furnace
Rated output (heat/sensible cool/total cool) (kBtu/h)	288/315/420	206/256/341
Rated air flow/minimum outside air (cfm)	12,597/1,585	9,527/1,585
Heating thermostat	70.0°F, set back to 65.0°F	70.0°F, set back to 65.0°F
Cooling thermostat	75.0°F, set up to 80.0°F	75.0°F, set up to 80.0°F
Heat/cool performance	Efficiency=80, EER=10.1	Efficiency=90, EER=13.0
Economizer?/type	No/not applicable	Yes/fixed dry bulb, 60.0°F
Duct leaks/conduction losses (total %)	2/0	2/0
Peak gains; internal lights, external lights, hot water, other; watt/ft^2	1.38/0.00/0.20/0.72	1.03/0.00/0.20/0.72
Added mass?	None	None
Daylighting?	No	Yes, continuous dimming
Infiltration (in^2)	Air changes per hour (ACH)=0.1	ACH=0.1

Table B-11. Annual Energy Use, Cost, and Emissions from ENERGY-10

	Base-Case Building	Sustainable Building
Simulation dates	Jan. 1 to Dec. 31	Jan. 1 to Dec. 31
Energy use (kBtu)	904,917	495,861
Energy cost ($)	16,058	9,208
Saved by daylighting (kWh)	–	25,011
Total electric (kWh)	183,542	108,238
Internal lights (kWh)	78,793	33,793
Cooling/fan (kWh)	35,242/17,106	19,066/2,977
Other (kWh)	52,402	52,402
Peak electric (kW)	83.8	50.6
Fuel (hot water/heat/total) (kBtu)	62,791/215,826/278,617	62,791/63,730/126,520
Emissions (CO_2/SO_2/NO_x) (lb)	279,585/1,481/789	160,414/869/460
Construction costs	3,146,828	3,195,257
Lifecycle cost	3,815,530	3,668,552

Table B-12. Cost of Modeled Energy Conservation Measures From ENERGY-10

Daylighting	Cost
Daylighting	13,371
Glazing (windows)	4,980
Shading	13,359
Energy-efficient lights	7,259
Insulation	18,868
Passive solar heating	-5,400
Economizer	5,041
High-efficiency HVAC	7,006
Total	**66,500**
Total after HVAC downsizing	**59,494**

Appendix C: A Sustainable Design Cost Study for the Johnson City Customer Service Center, Tennessee Valley Authority (TVA)[1]

This appendix describes an exercise undertaken by David Zimmerman of TVA to estimate the costs of adding sustainable design features to a building in the design phase.

C.1 Project Description

The proposed TVA Johnson City Customer Service Center (CSC) is a 24,171-ft^2 district office (see Figure C-1). The building design contains offices for employees, a large meeting room for TVA and community use (13,054 ft^2), support spaces (restrooms, showers, break room, storage, instrument room, and power crew room – 6,187 ft^2) and an enclosed heated vehicle bay (4,930 ft^2).

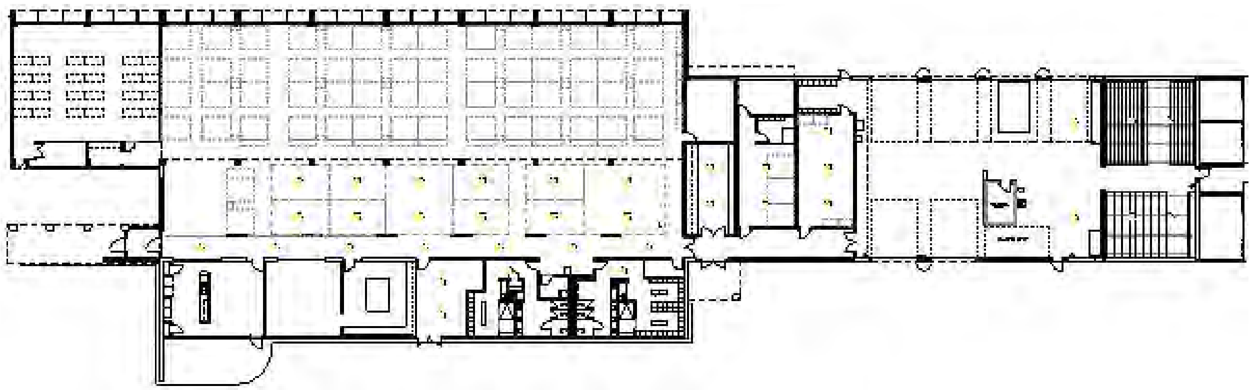

Figure C-1. Floor Plan of Johnson City CSC

C.2 Approach to Sustainable Design

The goal of the building design is to incorporate a wide range of cost-effective sustainable/energy technologies to demonstrate to TVA's customers its environmental commitment and to save energy and operations and maintenance (O&M) costs. The analysis described below is part of the initial design process. The process is similar to the approach described in Section 2.2 of this document for the prototypical building. The standard approach to efficient building design is to establish a base-case computer model of the building. The base case represents the building design without special attention to energy efficiency or sustainability. Then, various energy and sustainable technologies are added one at a time to see their impact on the base design. The cost and savings are determined, and those features found to have acceptable performance can be combined into final computer simulations to determine overall impact on the building design.

The Johnson City CSC project, like past TVA projects, underwent extensive planning and design prior to construction. Typically, every major new construction project undergoes an analysis similar to the one described below for Johnson City CSC.

[1] This appendix was written by D. Zimmerman, TVA.

C.3 Sustainable Features

The following technologies were examined for the sustainable version of the Johnson City CSC:

- **Decentralized geothermal heat pump HVAC system.** The building is heated and cooled using water to air heat pumps connected to a closed loop geothermal well system. To further reduce energy use, individual heat pumps units that use smaller pumps were connected to individual earth-coupled wells (instead of using one large well field and pump). This geothermal system cost more than a typical air-to-air heat pump, but the estimates show it pays for itself in 6.9 years as a result of energy and maintenance savings.
- **Light tube daylighting.** The building central circulation corridor, private offices, and meeting rooms are located in the interior of the building, far from exterior windows. To provide natural light to these spaces, 30 circular skylights that are 13 in. in diameter were connected to circular tubes lined with reflective material. These tubes "pipe" light to these interior areas. The light tubes, along with the switched control system to turn off electric lights when enough daylight was present, have an 8.3-year payback.
- **North clerestory daylighting to provide 50 footcandles.** The building design has a large open office area. Windows located on the south wall of this area provide daylight to a 15'-6" depth but cannot daylight the remaining 26'-6". Therefore, the roof was sloped upward and a six-foot-high continuous north facing clerestory was installed to daylight the rest of this area (see Figure C-2). Carefully sized overhangs and fins prevent direct-beam sunlight from entering the space. Continuous-dimming direct/indirect electric lighting systems were installed to maintain 50 footcandles over the whole space. The extra windows (those needed beyond what would have been installed in a conventional building), dimmable electronic light ballasts, a control system and light shelves were extra cost items attributed to the daylighting system and included in the incremental cost estimate. The analysis showed a payback of 6.5 years.
- **North clerestory daylighting to provide 15 footcandles of ambient light, with additional task lights.** This energy-saving option is the same as the option above, except fewer electric lights were installed and the control system was set to maintain a minimum light level of 15 footcandles. Task lights were added to each of the workstations. This energy-saving option has an even faster payback – 1.4 years.
- **Garage daylighting.** This energy-saving option involved adding north- and south-facing glazing to the vehicle bay to provide daylighting. The south-facing glazing also provides some passive solar heating. The cost of fiberglass glazing in place of metal panels and a control system to switch off the electric lights were included in the cost analysis. The payback was 5.5 years.
- **Light-colored roof (changing the absorptance 0.91 [dark] to 0.3 [white]).** Changing the metal roof from dark blue to white produced minimum savings. The base-case building uses a standard metal building roof system that calls for R-30 batts of insulation attached to the underside of the metal roof. This high level of insulation minimized the savings from this option, so the roof color has been left to the discretion of the architect.

In addition to the energy-saving options above, a wide range of additional technologies was investigated for incorporation into the design. Most of these can be classified as sustainable and are as follows:

- **Membrane energy recovery heat exchanger.** This is a relatively new technology that involves transferring heat and moisture between incoming ventilation air and outgoing exhaust air using a thin membrane. The manufacturer had a prototype unit and wanted to install it and monitor performance. If successful, such a unit could pay for itself in energy savings in 3 to 4 years.

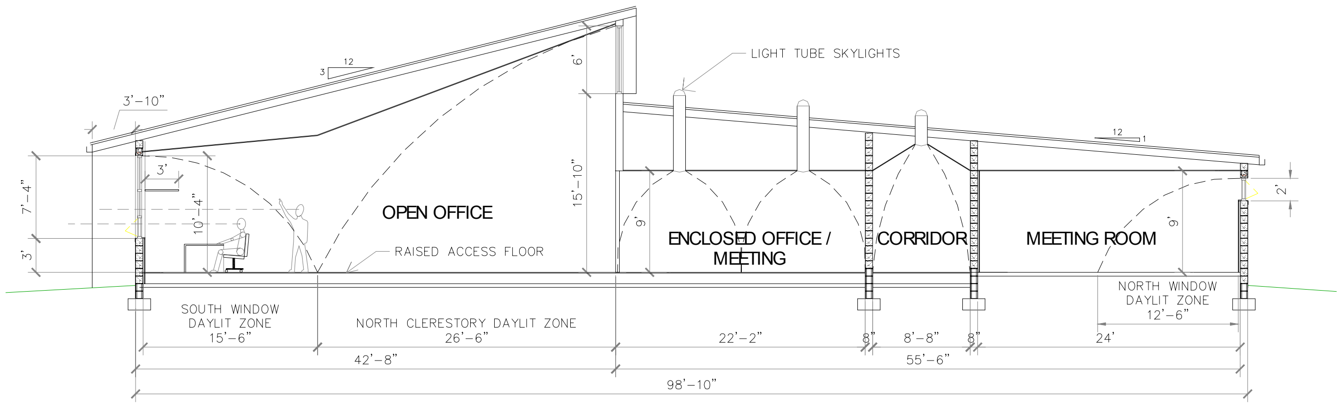

Figure C-2. Typical Section of Johnson City CSC, Showing Clerestory Windows

- **Using ultraviolet (UV) light to treat HVAC supply air.** This technology involves passing HVAC supply air through ductwork lined with UV light tubes. UV light is very effective at killing bacteria. Such a system would not have an easily quantified savings. It uses additional electricity to operate but could have a payback based on employee wellness (less absenteeism).
- **Metal roof vs. asphalt roof.** Typical roofs on small commercial buildings are either built-up asphalt or asphalt-based shingles. A heavy-gage standing-seam metal roof can have substantially longer life compared with asphalt and is easily recycled, making it a more sustainable choice. Analysis showed that the extra cost of a metal roof would pay for itself in 6.6 years, so it was included in the design.
- **Permeable pavement.** Permeable pavement allows water to drain through to the ground below. Such pavement prevents water runoff and erosion. New forms of permeable asphalt pavement were found to be almost identical in cost to standard asphalt pavement. Permeable pavement also reduces the need for storm water catchment structures and storage making permeable pavement an instant payback.
- **Rain water collection for irrigation and vehicle washing.** This sustainable option involved collecting rainwater off the roof and storing it for use in a 7500-gallon aboveground tank. The water would be used for washing vehicles and irrigating landscaping. This option was estimated to have a 9.4 –year payback.
- **Climate appropriate plants.** Research showed that climate-appropriate plants for TVA's climate in most cases cost no more than imported plants. Climate-appropriate plants were included in the design.
- **Autoclaved concrete block.** Autoclaved concrete block covered with a manufacturer-approved exterior stucco material was included in the design. This sustainable material contains recycled-content (fly ash) and has excellent insulation qualities. The cost of this block was found to be equal to standard concrete block with the addition of rigid insulation, resulting in no extra cost.
- **Waterless urinals compared with standard urinals.** Waterless urinals were found to cost less to install and maintain than standard urinals. They are fiberglass units with a vapor trap that contains a liquid that allows urine to pass through. They do not require a water supply line, flush valves, etc., resulting in substantial water and maintenance savings.
- **High-velocity electric hand dryers – Excel Xlerator® compared with paper towels.** The Excel Corporation markets a hand dryer that it claims can dry hands in 10 to 12 seconds compared with standard dryers, which can take up to 30 seconds. Two of these hand dryers were added to the design; and if fully used, they will reduce the use of paper towels. The projected payback for the dryers cost is 1.6 years compared with paper towel use and disposal.

- **Sustainable (healthy) interior finishes.** Low volatile organic compound (VOC) paints and finishes along with materials with recycled content and the ability to be recycled have been gradually introduced into TVA renovation and new construction work and were included in the CSC design.

Some options were considered but not included in the design:

- **Operable windows for ventilation.** This option was briefly considered and rejected because of the high humidity levels and very hot summers. The installation of a very efficient HVAC system (geothermal heat pump) further reduces the potential of this option to save money and provide comfortable indoor conditions.
- **Wind electric generation.** This energy option was not included because the current building site does not have the necessary wind levels.
- **Photovoltaic roof canopy.** Replacing the covered parking canopy with a canopy made up of photovoltaic cells was found to be very costly and to have a very long payback period.

In addition to the above sustainable technologies, a decision had already been made to incorporate the following sustainable technologies, so they were included in the base-case cost:

- Raised access floor to provide flexibility in changing the spaces and to provide underfloor HVAC with individual work station air controls
- Movable walls to construct interior private offices and meeting rooms to minimize the use of drywall and provide easy changes to the space in the future.

C.4 Financial Considerations

Figure C-3 (at the end of the appendix) shows the calculated incremental first costs and annual cost savings (with payback periods). In addition to the individual technologies described above, the analysis included a number of combinations of technologies:

- **Total building daylighting (north clerestory – 50 footcandles).** This is a combination of light tube daylighting, garage daylighting, and open office north clerestory daylighting to 50 footcandles. This combination yielded a payback of 7.5 years.
- **Total building daylighting (north clerestory – 15 footcandles).** This is the same as the option above, except the open office area is lit to only 15 footcandles, and task lights are installed in each of the workstations. This combination yielded a payback of 5.0 years.
- **Total building daylighting (50 footcandles) plus geothermal heat pump.** This is a combination of total building daylighting (north clerestory – 50 footcandles) and the geothermal heat pump HVAC system. This combination yielded a payback of 6.9 years.
- **Total building daylighting (15 footcandles) plus geothermal heat pump.** This is the same as the option above (daylighting combined with geothermal heat pump), except the open office area is being lit to only 15 footcandles, and task lights are installed in each of the workstations. This combination yielded a payback of 5.7 years. The significance of this combination is that overall energy use of the building design was reduced by almost 50%.

The energy cost savings of the energy-saving options (daylighting and geothermal heat pump system) were determined by creating an energy model of the building using the PowerDOE building energy analysis program (Version 1.18g by James J. Hirsch & Associates), which uses DOE-2.1 as the principal underlying model (see Section 3.1 and Appendix B for description of how DOE -2.1 was applied in this study). This program takes into account all the heat loss/gain through the various building surfaces and the amount of internal energy use and heat gain from lights, people, and equipment and models the HVAC system to maintain set indoor conditions. The program performs an hour-by-hour simulation of the building design and outputs a wide range of reports, including yearly energy cost based on utility rate structure.

The costs of the various energy-saving options were determined using several approaches. The geothermal heat pump system size and cost were determined by a TVA engineer experienced in designing such systems for TVA customers. The cost of daylighting components were determined from "RS Mean Building Construction Cost Data – 2002" (RS Means 2002) along with some actual numbers from specific manufacturers.

C.5 Key Conclusions for the Business Case

Many cost-effective sustainable design options exist. Energy reduction of 50% from the base case design, with a payback period of 5.7 years, was projected for this building by adding many daylighting features, very low light levels, and a geothermal heat pump. Lighting options can be very cost-effective because they tend to lower first costs.

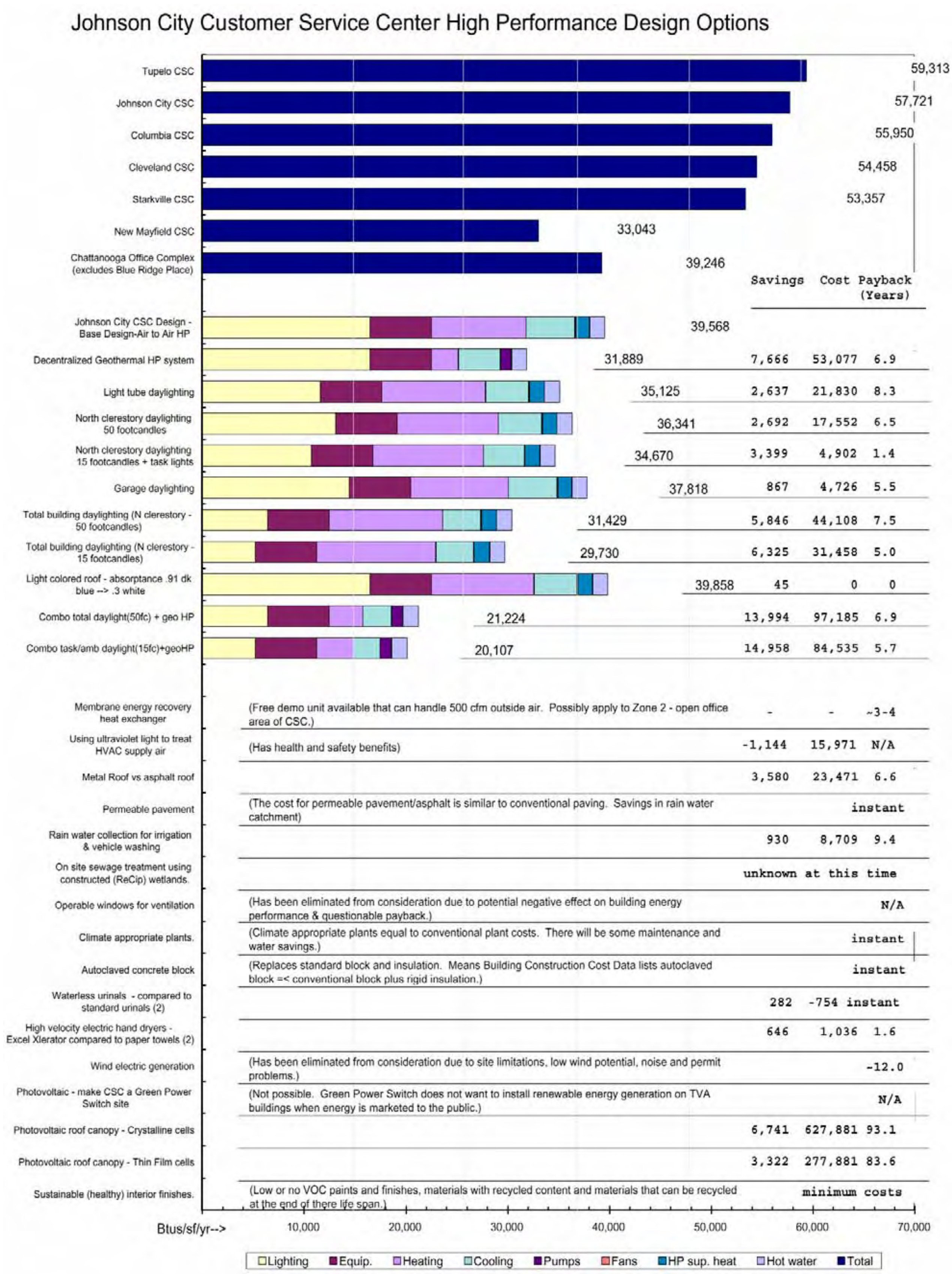

Figure C-3. Analysis of Sustainable Features for Johnson City CSC

How to Read Figure C-3

The "Johnson City Customer Service Center High Performance Design Options" bar chart is divided into three sections. ***The solid bars*** at the top show actual energy performance of existing customer service center buildings along with the Chattanooga Office Complex, which is one of TVA's most energy-efficient office buildings. These solid bars provide a reference to which to compare the Johnson City CSC design. (The units are Btu/ft^2/yr.)

The multicolored bars show the performance of the "base" Johnson City CSC design, as well as the individual technologies considered and the combinations of energy-saving options. Each color shows the amount of energy going to the various component energy uses within the building such has lighting, equipment, heating, etc. (shown at the bottom of the chart). All the energy-use bars are in units of Btu/ft^2/year, which makes it easy to not only compare to the solid reference bars but to other non-TVA buildings.

Data for ***technologies listed below the bars*** are primarily sustainable technologies that don't have energy savings but have other types of cost savings (or in some cases have no additional costs compared with standard technologies) Those showing less than a 10-year payback, an instant payback, or low costs have been recommended for incorporation into the design.

Appendix D: Documentation of the Sustainable Siting and Water-Savings Features Included in the Prototype Building Analysis[1]

This appendix documents the calculations used to estimate costs and cost savings associated with siting and water-efficiency technologies and materials described in Section 2.3 and 2.4: water-efficiency features (Section D.1), stormwater management (Section D.2), and landscape management (Section D.3).

D.1 Water-Efficiency Features

D.1.1 Domestic Water Technology Selection

Typical domestic fixtures that are found in an office building are faucets, toilets, urinals, and showerheads. For the prototype building, highly efficient fixtures were selected to exceed the minimum flow rate standards set by the Energy Policy Act (EPAct) of 1992. The following summarizes the advanced technologies that were selected (also see Table D-1).

- **Showerheads.** EPAct mandates that showerheads not exceed 2.5 gallons per minute (gpm) at a pressure of 80 pounds per square inch (psi) or less. Typical building pressure is between 40 and 80 psi. To exceed this standard, a showerhead of 2.0 gpm was chosen. More efficient showerheads are available, but the quality of the shower can be greatly diminished with less than 2.0 gpm.
- **Faucets.** EPAct sets standards that kitchen faucets cannot exceed 2.5 gpm at 80 psi and restroom faucets cannot exceed 2.2 gpm at 80 psi. For both the kitchen and restroom faucets, a 1.0 gpm model was chosen for the prototype building.
- **Toilets.** EPAct guidelines mandate that all toilets not exceed 1.6 gallons per flush (gpf). Two advanced technologies were analyzed for the prototype building: a dual-flush toilet and a 1.1-gpf model. A dual-flush toilet has two flushing options – liquid flushing at 0.8 gpf and solid flushing at 1.6 gpf. An analysis of the two toilets proved the dual-flush toilet to be the most economical option. The 1.1-gpf toilet is an emerging technology with a very high initial cost – the simple payback was calculated to be up to 30 years. The dual-flush toilet was only analyzed for the women's restrooms. It was assumed that when men use toilets (in combination with urinals), the 1.6-gpf option would always be used; therefore, no water savings would occur from the dual-flush toilet in the men's restrooms.
- **Urinals.** EPAct requires that all urinals not exceed 1.0 gpf. A no-water urinal was chosen for the advanced technology for this study. No-water urinals have a lower installation cost because no water supply line is necessary. Therefore installing a no-water urinal is less expensive than the low-flush model.

D.1.2 Incremental Costs and Annual Water Savings

For indoor domestic water technology, the incremental capital and installation costs, annual water consumption and cost savings, and the simple payback were estimated. For each domestic fixture found in typical office buildings (faucets, toilets, urinals, and showerheads), a more advanced fixture was chosen that exceeded the minimum flow rate standards set by the EPAct and that kept quality as a parameter. Maintenance costs were considered when analyzing urinals because of differing costs for standard urinals compared with no-water urinals.

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[1] Prepared by K. McMordie-Stoughton and G. Sullivan, Pacific Northwest National Laboratory.

Table D-1. Domestic Water Technology Overview

Equipment	Standard Equipment (set by EPAct)	Advanced Equipment
Showerheads	2.5 gpm	2.0 gpm
Faucets	2.5 gpm – kitchen 2.2 gpm – restroom	1.0 gpm (both kitchen and restroom)
Toilets	1.6 gpf	Dual flush: 0.8 and 1.6 gpf options
Urinals	1.0 gpf	0 gpf

When annual water cost savings were calculated for each fixture type, water rates were broken by low, high, and average, based on fiscal year 1999 water rates from General Services Administration (GSA).[2] Each fixture's water use was calculated by using the standard use frequency for each fixture type for the prototype building. The total water reduction for indoor domestic water using equipment was over 47%. Note that the energy cost savings from hot water savings were not calculated or included. All assumption and data sources used to calculate these values are detailed in Table D-2.

D.2 Stormwater Management

The goals of sustainable stormwater management are to maintain stormwater on site as long as possible to reduce runoff volume, to reuse the stormwater, and to ensure that it is clean before returning it to the natural system, which reduces nonpoint source pollution and sedimentation in natural water ways. For this analysis, an integrative stormwater management system comprised of a gravel-paved parking lot and underground rainstorm system was examined.[3]

This porous, gravel-paved parking area is a heavy load-bearing structure that is filled with porous gravel, allowing stormwater to infiltrate the porous pavement and to be moved into a rainwater collection system. This system will greatly reduce runoff and retain rainwater on site for landscape irrigation; by contrast, a conventional asphalt parking area would cause all stormwater to run off the site, increasing pollutant concentrations and eliminating the possibility of reusing the water. The porous gravel system was selected for several reasons:

- As an integrative system, it achieves the goals of maintaining and using stormwater on site.
- The materials are partly made from recycled material.
- Cost and maintenance data are reliable.
- It meets the Environmental Protection Agency's National Pollutant Discharge Elimination System (NPDES) Phase II requirements, which expand the existing NPDES to require a storm water management program for all new construction, including runoff control and post-construction stormwater management. (For more information, see http://www.epa.gov/fedrgstr/EPA-WATER/1999/December/Day-08/w29181a.htm.)

[2] Personal Communications with A. Walker of General Services Administration, February 13, 2001.
[3] Invisible Structures, Inc., provided an integrative stormwater management system from Gravelpave and Rainstore products.

Table D-2. Assumptions and Data Sources

		Data Source
Number of working days per year	235	Based on 10 holiday days and 15 vacation days
Occupancy	97	Standard for prototype building
Distribution of women and men	50%/50%	
Restroom uses		Standard usage
Women's		
Toilet use/day/person	3	
Men's		
Toilet use/day/person	1	
Urinals use/day/person	2	
Faucets	3	
Faucet duration	30 sec	
Shower use/day	1	
Shower duration	7 min	
No. of fixtures in prototype building		Uniform Building Code (1997) and Dziegielewski et al. (2000)
Restrooms	4	
Toilets	8	4 in women's bathrooms and 4 in men's
Urinals	3	
Faucets	8	
Kitchen faucets	1	
Showers	2	
Water rates - $/1000 gallons		GSA Fiscal Year 1999
GSA Region 3 average (Baltimore is in Region 3)	$3.97	
Costs for fixtures (per unit)		
Showerheads		
Standard	$4.00	GSA's Federal Supply Service provided through website: https://www.gsaadvantage.gov
Advanced	$8.99	Catalog supplied by Niagara Conservation Company, Cedar Knolls, New Jersey, 2002
Faucets		
Standard	$3.40	GSA's Federal Supply Service provided through website: https://www.gsaadvantage.gov
Advanced	$9.27	GSA's Federal Supply Service provided through website: https://www.gsaadvantage.gov
Toilets		
Standard	$150.00	GSA's Federal Supply Service
Advanced	$200.00	Dual-flush toilet from Caroma: personal communication with representative of USA Caroma, Inc., May 2002
Urinals		
Standard	$216.78	GSA's Federal Supply Service provided through website: https://www.gsaadvantage.gov

		Data Source
Advanced	$127.60	GSA's Federal Supply Service provided through website: https://www.gsaadvantage.gov
Installation costs for urinals		Personal communication with Waterless urinal and Falcon Water Free Company, May 2002
Standard	$200.00	(Total cost for installation of unit and water supply line)
Advanced	$100.00	(No water supply line needed)
Annual maintenance costs for urinals		Based on information provided through personal communication with D. Zimmerman, Tennessee Valley Authority, regarding Johnson City Customer Service Center (see Appendix C)
Standard urinal	$119.00	
Blue seal fluid	$14.85	
Eco-trap	$11.44	
Savings for dual flush toilets	33%	Based on one 1.6 gpf/day and two 0.8 gpf/day/woman
Supply and distribution – typical	3	
Wastewater treatment – activated sludge	1.7	

D.2.1 Assumptions and Data Sources

To estimate the costs and annual savings associated with an integrative stormwater management system, detailed assumptions were made based on available data sources, which are described in the following sections.

Parking Area

For the parking area, the porous, gravel-paved lot was compared with a traditional asphalt parking area. The assumptions and data sources for the comparative analysis are as follows:

- Parking lot surface area assumptions:
  - The total lot size is 1 acre – A review of the zoning ordinances, including those in the Baltimore area, led to this size assumption.
  - The parking lot area will require 50 to 75 parking spaces.
  - The parking lot dimensions are assumed to be 140 ft by 180 ft, giving a total area of 25,200 ft^2.

- Installation costs for the porous, gravel-paved and asphalt parking lot came directly from communications from the products manufacturer:[4]
  - Gravel-paved – $2.30/$ft^2$
  - Asphalt – $2.11/$ft^2$.

- Maintenance costs were obtained from a University of South Alabama study (1999), which shows a comparison of maintenance costs between an asphalt parking lot and porous gravel and grass-paved system:
  - Gravel/grass paved parking area – $0.296/$yd^2$/yr
  - Asphalt parking area – $0.497/$yd^2$/yr.

[4] Direct communications with D. Glist of Invisible Structures, Inc., on June 28, 2002, provided estimated costs for Gravelpave product and conventional asphalt-paved surface.

This study examined the historical records of the University of South Alabama Grounds Department asphalt maintenance from 1993 to 1998 and compared those records with the maintenance costs for a porous gravel and grass-paved system that was installed on campus. For the asphalt parking lots, maintenance costs included coating, paint striping, patching and crack filling, and resurfacing. For the grass/gravel-paved parking area, maintenance included regular landscaping requirements of the grass and periodic raking and topdressing of the gravel.[5] A 20-year life span was assumed for both surfaces.

Rainwater Collection System

An integrated rain storage system, Rainstore, was compared with a conventional corrugated plastic pipe system. The conventional system simply moves the stormwater off the asphalt parking lot but does not include the opportunity to reuse the stormwater for irrigation. The assumptions and data sources for the comparative analysis are as follows. Both the Rainstore and corrugated pipe systems were sized for the site using Rainstore Materials Estimator, an online tool[6] that allows the user to input the site characteristics and stormwater storage needs to estimate the amount of materials required for a Rainstore system. Optional designs such as the corrugated pipe system can also be evaluated.

Installation costs associated with the Rainstore system were obtained from a quote[7] from a Northeast product dealer, based on the materials that were estimated in the Rainstore Materials Estimator. The Rainstore manufacturer provided costs for additional materials and fees:

- Rainstore modular units – $35,638[7]
- Geogrid and geotextile – $2519[7]
- Pump for feeding rainwater to irrigation system – $300[7]
- Freight for shipping Rainstore system – $7500.[7]

Installation costs for the corrugated pipe system were provided by the product manufacturer[7] and were based on the materials that were estimated in the Rainstore Material Estimator:

- Corrugated pipe – $37,310[7]
- Other materials and services required – $21,154.[7]

Labor costs for both the Rainstore system and corrugated plastic pipe were as follows:

- Labor cost – $70/hr[7]
- Total labor required for Rainstore – an estimated 45 hours (from the Rainstore Estimator tool)
- Total labor required for the corrugated pipe system – assumed to be 5% additional for extra welding of elbows and tees into the system that the Rainstore system does not require.[8]

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[5] Because the system examined in this analysis did not include a grass-paved system, the maintenance costs comparison can be assumed to be conservative.

[6] The website for the online tool is available at http://www.invisiblestructures.com/RS3/RS3_Est_Instruct.htm.

[7] ACF Environmental – a distributor in the Northeastern US for Rainstore products – quotation for Rainstore Stormwater Storage System, July 29, 2002.

[8] Direct communications with C. Spelic of Invisible Structures, Inc., on July 31, 2002, provided estimated costs for labor, freight, and other associated costs with the Rainstore system and for a corrugated pipe systems based on material prices for piped system.

D.2.2 Incremental Costs and Annual Savings Calculations

Tables D-3 through D-5 summarize the calculations that estimated the incremental cost for the sustainable stormwater management system. Table D-3 itemizes all individual costs and fees and shows how the total cost was calculated for each system (summation of the cost column in Table D-3). The total cost for the conventional corrugated pipe system was subtracted from the Rainstore system to calculate the incremental installation cost, as shown on the last row of Table D-3.

Table D-4 lists the installation and maintenance costs for the porous gravel parking area compared with the asphalt parking area. The installation cost per square foot was multiplied by the total area of the parking area, which is 25,200 ft^2, to calculate the total installation cost. To determine the incremental installation cost, the cost of the asphalt parking lot was subtracted from the gravel-paved lot. The incremental maintenance cost was determined in the same manner as shown in Table D-4.

In Table D-5, the total incremental cost for the entire system was calculated by combining the costs for the parking area and rainwater collection system for both the sustainable design and conventional design – as shown in the rows labeled "Total" in Table D-5. The incremental cost was then calculated by subtracting the two total costs. The simple payback of 5.59 years can be calculated by dividing the incremental installation cost by the total maintenance savings.

D.3 Landscape Management Overview and Assumptions[9]

Sustainable landscaping practices combine sound maintenance practices with a design that uses native plants. Conventional landscaping usually is comprised of turf, such as Kentucky blue grass, which requires an irrigation system to provide supplemental water, high maintenance to provide regular mowing, chemical herbicide application to reduce weeds, and fertilizer to maintain a healthy lawn in most regions of the United States. Planting native species greatly reduces the need for supplemental watering and regular maintenance. Native species will withstand the conditions of the area, so native plants can survive in both abnormally wet and dry conditions, whereas non-native plants do not adapt as well to extreme conditions. Also, with sustainable designed landscape, rainwater can be harvested to serve as supplemental irrigation. Specific plants can be selected to help clean rainwater's impurities such as oil from automobiles and salts from roadways to return filtered water to the groundwater or stormwater system.

The following "design" assumptions summarize the specifics of the landscaping area analysis of the site (more details on these features are covered in the next section):

- Landscaping area – 8,000 ft^2
- Landscape design – Native seed mixture combination of native warm weather turf and wildflowers create a natural "meadow" area.
- Irrigation system – Spot and periodic watering are required to establish the native plants. All of the the irrigation water required to establish the native landscaping will be harvested from the rainwater held in the stormwater management system.
- Landscape maintenance – The sustainable landscaping area requires very little maintenance, while the traditional turf landscaping requires regular maintenance and chemical treatment.

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[9] K. McMordie, Pacific Northwest National Laboratory.

Table D-3. Installation Costs for Rainwater Storage and Conventional Stormwater Management Systems

	Type	Material Amount	Units	Unit Cost	Cost
Rainstore system	Rainstore modular units	2232	units	$15.97	$35,638.38
	Geotextile	1378	yd^2	$0.55	$760.00
	Geogrid	459	yd^2	$3.83	$1,759.04
	Pump for irrigation feed				$300.00
	Excavation	569	yd^3	14	$7,966.00
	Backfill	226	yd^3	$12.00	$2,712.00
	Area needed	1001	ft^2	NA*	No cost associated with area
	Cover	51	yd^3	$12.00	$612.00
	Freight	3	truck loads	$2,500.00	$7,500.00
	Labor	45	hours	$70.00	$3,150.00
Total					$60,397.42
Conventional system	Corrugated 48" plastic pipe	533	linear ft	$70.00	$37,310.00
	Tees	8	each	$900.00	$7,200.00
	Elbows	4	each	$700.00	$2,800.00
	Excavation	543	yd^3	14	$7,602.00
	Backfill	197	yd^3	$12.00	$2,364.00
	Area needed	2665	ft^2	NA*	No cost associated with area
	Cover	99	yd^3	$12.00	$1,188.00
	Freight	NA	No freight needed	No freight needed	No freight needed
	Labor	47.5	hours	$70.00	$3,325.00
Total					$61,789.00
Incremental installation cost (Rainwater minus conventional)					-$1,391.58
* NA – Not applicable.					

Table D-4. Installation and Maintenance Costs of Porous Gravel Parking Area and Conventional Asphalt Parking Area

	Installation Cost/Ft²	Total Installation Cost	Maintenance Costs ($/ft²/yr)	Total Maintenance Costs/Yr
Gravel-paved parking lot	$2.30	$57,960	$0.0329	$828.80
Asphalt parking lot	$2.12	$53,424	$0.0552	$1,391.60
Incremental cost (gravel minus asphalt)		$4,536		-$562.80

Table D-5. Total Stormwater Installation, Maintenance, and Incremental Costs

	Total Installation	Total Installation Cost	Maintenance	Total Annual Maintenance Cost ($/Kft²-yr*)
Sustainable system				
Rainstore	$60,397			
Gravel paved	$57,960			
Total	$118,357	$5,918	$829	$41
Conventional system				
Corrugated pipe system	$61,789			
Asphalt-paved parking area	$53,424			
Total	$115,213	$5,761	$1,392	$70
Incremental cost (sustainable minus conventional)	$3,144	$157	-$563	-$28

D.3.1 Assumptions and Data Sources

To estimate the installation costs and annual savings associate with landscaping at the site, the following assumptions and data sources were used in the analysis:

- Landscape area
  - Total lot size is 1 acre – A review of zoning ordinances, including those in the Baltimore area, led to this assumption.
  - The parking area – A total of 25,200 ft² based on 50 to 75 parking spaces.
  - Footprint of the building – 10,082 ft².
  - Landscaping area – 8000 ft² (with the remaining area of 278 ft² for sidewalks).
- Landscape materials and installation cost:[10]
  - $20,000/acre for native planting of seed mixture
  - $6667/acre for traditional turf (one-third the cost of native seed mixture).

- Irrigation system –Normally, no irrigation system would be installed for a native landscape, but because this landscape will be irrigated from rainwater in an underground storage system, a pump (costs for the pump was included in the stormwater management analysis) is required to

[10] Input on the design and installation costs for native plant and traditional turf material was provided by G. Gardner of Davis, Gardner, Gannon, Pope Architecture in Philadelphia, Pennsylvania. This firm has been involved in two Leadership in Energy and Environmental Design (LEED™) projects in the northeastern United States and is knowledgeable about the real costs associated with native plant species compared with traditional turf for the northeastern United States.

pump the water from the underground storage, and an irrigation system is required to provide a means to deliver the rainwater to the landscaping. This system is the same size required for a conventially-landscaped area; therefore, there is no incremental cost for the irrigation system.

- Maintenance services and costs[11]
  - Annual maintenance for the traditional turf area will require 6 applications of fertilizer and herbicides per year, 26 mowing and maintenance trips, and 1aeration.
  - The annual maintenance fee for the sustainable landscape is assumed to be 10% of that of the traditional landscape. While sustainable landscaping will not require routine maintenance such as mowing and fertilizing, it is not maintenance-free. Based on a review of the literature in this area, a traditional turf landscape area is estimated to require 10 days of maintenance, whereas a sustainable design will only require 1 day. The watering schedule for traditional turf landscaping is assumed to be 1 in. of water over the entire area at 30 applications per year.
  - The average FY 1999 GSA water rate for Region 3 (Baltimore is in GSA Region 3) was used to estimate the cost of irrigation for traditional turf area: $3.97/1000 gallons.
  - No water costs are associated with the native landscaping because all supplemental water will be supplied from the rainwater collection system.
  - Annual maintenance service fees for traditional turf landscape are assumed to be $2754 (a combination of all services listed and irrigation requirements). This cost does not include maintenance of the irrigation systems because the maintenance costs are assumed to be minimal and not a large factor in this study because both designs have irrigation systems.

D.3.2 Incremental Costs and Annual Savings Calculations

Table D-6 shows the individual installation and maintenance costs estimated for the sustainable and conventional landscape designs. The installation costs are a combination of design, implementation of landscape materials, and installation of the irrigation system. The maintenance costs are a combination of all routine maintenance (listed above) and cost of water to irrigate the landscaping. The incremental costs were determined by calculating the difference between the total costs for each design, as shown in the last row of Table D.6. The simple payback of 0.8 years can be calculated by dividing the incremental installation cost by the total maintenance savings.

[11] The cost for landscape maintenance for traditional turf was estimated by Trugreen Chemlawn Company, a division of the national franchise, located in Baltimore, Maryland.

Table D-6. Installation, Maintenance, and Incremental Costs of Sustainable and Conventional Landscape Area

	Site Design and Implementation ($/acre)	Site Design and Implementation ($ for this site)	Installation Cost ($/1000ft^2*)	Maintenance Costs ($/yr)	Irrigation Water Use Cost ($/yr)	Total Maintenance Cost ($/yr)	Total Maintenance Cost ($/1000 ft^2)
Sustainable Design							
Native planting	$20,000	$3,673.09	$183.65	$272.39	$0	$272.39	$13.62
Conventional							
Traditional turf	$6,667.67	$1,224.36	$61.22	$2,723.91	$593.91	$3,317.82	$165.89
Incremental cost (sustainable minus conventional)	$13,333	$2,498.73	$122.44	-$2,451.52	-$593.91	-$3,045.43	-$152.27

Appendix E: Documentation of the Sustainable Materials Features Included in the Prototype Building Analysis[1]

This appendix documents the calculations used to estimate costs and cost savings associated with the sustainable materials features in the prototype building analysis described in Section 2.1:

- Low-emitting paint versus latex paint (Section E.1)
- Recycled latex paint (Section E.2)
- Concrete with slag content (Section E.3)
- Concrete with fly ash content (Section E.4)
- Carpet with recycled content (Section E.5)
- Certified wood options (Section E.6).

E.1 Documentation of Costs of Low-Emitting Paint Versus Typical Latex Paint

Based on cost estimates from the Timberline model (see Appendix B), the 20,000-ft^2 office building has 70,000 ft^2 of interior painted surface. The painted surface was assumed to be primed and then painted with a typical contractor-grade latex paint (eggshell).

To provide paint quality comparisons, data on high-end products were also gathered. Sales representatives from three major paint manufacturers were contacted, and primer and topcoat paint prices were provided. In addition, the vendor technical data sheets provided coverage rates (square feet covered per gallon of paint). The calculations for this document assumed the midpoint of the price range and the lower end of the coverage range to offer a conservative comparison of the products.

Low-emitting (no-volatile organic compound [VOC]) paint provides better working conditions at the construction site and may allow painters to work inside the building while other activities are underway. The cost of the paint varies depending on the location of the purchase, volume of paint purchased, and the ability of the local distributor to offer special rates. The specifications for all the low-emitting paints analyzed in this study stated that the VOC content was 0 milligram/liter.

The sales representatives suggested alternative surface preparation techniques (in addition to a traditional primer), but those techniques are not discussed here because the products were too different to offer a fair comparison.

E.1.1 Benjamin Moore Paint Company

A Benjamin Moore sales representative provided price quotes for three types of paint used in commercial buildings: a very high-end latex paint (AquaVelvet), a typical contractor-grade latex paint (SuperSpec), and a low-emitting paint (EcoSpec). The technical data sheets state that the EcoSpec primer has a higher coverage rate than the other paints. Table E-1 shows the ranges quoted by the vendor for the estimated retail price and coverage rates and the values used in the calculations.

[1] This appendix was written by K. Fowler, D. Hostick, and K. Poston, Pacific Northwest National Laboratory.

Table E-1. Prices and Coverage Rates for Benjamin Moore Paints

Paint Type	Price Range (per gal)	Price Assumed for the Calculations	Coverage (ft^2/gal)	Coverage Rate Assumed for the Calculations
Typical contractor latex paint (SuperSpec)				
Primer	\$15.28-\$15.79	\$15.54	400-500	400
Top coat	\$22.80-\$22.99	\$22.90	400-450	400
Very high-end latex paint (Aquavelvet)				
Primer	\$24.88-\$24.99	\$24.94	400-450	400
Top coat	\$29.88-\$29.99	\$29.94	400-450	400
Low-emitting latex paint (EcoSpec)				
Primer	\$21.50-\$22.00	\$21.75	550	550
Top coat	\$28.40-\$28.80	\$28.60	400-450	400

Using the values in Table E-1, the material cost for painting 70,000 ft^2 of wall area in the 20,000-ft^2 office building is as follows (assuming one coat of primer and one top coat and a 19.6% adder for sales tax, contractor bonds and insurance, profit and overhead, and general conditions based on the Timberline model).

The material cost for SuperSpec is as follows:

Primer coat cost	=	((70,000 ft^2)/(400 ft^2/gal)) x \$15.54/gal = \$2719.50
Top coat cost	=	((70,000 ft^2)/(400 ft^2/gal)) x \$22.90/gal = \$4007.50
Total material cost	=	\$2719.50 + \$4007.50 = \$6727
Full cost (inc. adder)	=	\$6727 x 1.196 = **\$8045.49**

The same calculation was done for AquaVelvet and EcoSpec, resulting in full costs (inc. adder) of \$11,486.38 and \$9296.72, respectively.

The differences between EcoSpec (the non-VOC paint) and the other two paints are as follows.

The material cost for EcoSpec compared with SuperSpec is as follows. The difference per gallon for the primer is \$21.75 - \$15.54 = \$6.21 (EcoSpec is more expensive by \$6.21 per gallon). The difference per gallon for the top coat is \$28.60 - \$22.90 = \$5.70. The total first cost difference is \$9296.72 - \$8045.49 = \$1251.23 or, by dividing by 20,000 ft^2 of building floor space, the difference in first cost is \$62.59/1000 ft^2.

Using the same calculation procedure, the difference in first cost (inc. adder) for EcoSpec compared with AquaVelvet is -\$109.46/1000 ft^2.

E.1.2 Sherwin Williams Paint Company

A Sherwin Williams sales representative provided price quotes for three types of paint used in commercial buildings: a high-end latex paint (ProMar 400), a typical contractor-grade latex paint (ProMar 200), and a low-emitting paint (Harmony). The technical data sheets state that the

Table E-2. Prices and Coverage Rates for Sherwin Williams

Paint Type	Price Range (per gal)	Price Assumed for the Calculations	Coverage (ft^2/gal)	Coverage Rate Assumed for the Calculations
Typical contractor latex paint (ProMar 400)				
Primer	$9.50-10.00	$9.75	350-400	350
Top coat	$10.50-12.50	$11.50	350-400	350
Very high-end latex paint (ProMar 200)				
Primer	$11.00-12.50	$11.75	350-400	350
Top coat	$13.00-14.50	$13.75	350-400	350
Low-emitting latex paint (Harmony)				
Primer	$13.00-14.50	$13.75	350-400	350
Top coat	$15.00-17.00	$16.00	350-400	350

coverage rates are the same for each product. Table E-2 shows the ranges quoted by the vendor for the estimated retail price and the coverage rates and the values used in the calculations.

Using the values in Table E-2, the material cost for painting 70,000 ft^2 of wall area in the 20,000-ft^2 office building is as follows (assuming one coat of primer and one top coat and a 19.6% adder for sales tax, contractor bonds and insurance, profit and overhead, and general conditions, based on the Timberline model).

The material cost for ProMar 400 is as follows:

Primer coat cost	=	((70,000)/(350 ft^2/gal)) x $9.75/gal = $1950
Top coat cost	=	((70,000 ft^2)/(350 ft^2/gal)) x $11.50/gal = $2300
Total material cost	=	$1950 + $2300 = $4250
Full cost (inc. adder)	=	$4250 x 1.196 = **$5083**

The same calculation was done for ProMar 200 and Harmony, resulting in full costs (inc. adder) of $6099.60 and $7116.20, respectively.

The differences between Harmony (the low-emitting paint) and ProMar 400 are as follows. The difference per gallon for the primer is $13.75 - $9.75 = $4.00 (Harmony primer is more expensive by $4 per gallon). The difference per gallon for the top coat is $16.00 - $11.50 = $4.50. The total first cost difference is $7116.20 - $5083 = $2033.20 or, by dividing by 20,000 ft^2 of building floor space, the difference in first cost is $101.66/1000 ft^2.

Using the same calculation procedure for Harmony compared with ProMar 200 yields a difference in first cost of $50.83/1000 ft^2.

E.1.3 Duron Paint Company

A Duron sales representative provided price quotes for four types of paint used in commercial buildings: premium-quality latex paint (Plastic Kote 29-series), top-quality latex paint (Ultra Deluxe 36-series), a typical contractor-grade latex paint (Pro Kote 23-series), and a low- emitting paint

(Genesis 79-series). The technical data sheets state that the coverage rates are the same for each product. The sales representative recommended the same primer regardless of top coat choice.

Table E-3 shows the ranges quoted by the vendor for the estimated retail price and the coverage and shows the values used in the calculations. Note that Duron paint is manufactured in Atlanta, Georgia, and Beltsville, Maryland. Procuring paint for the Baltimore prototype building from the Duron location in Maryland would contribute to local/regional material points in the LEED certification process.

Table E-3. Prices and Coverage Rates for Duron

Paint Type	Price Range (per gal)	Price Assumed for the Calculations	Coverage (ft^2/gal)	Coverage Rate Assumed for the Calculations
Typical contractor latex paint (Pro Kote 23-Series)				
Primer	$13.85-14.85	$14.35	350-400	350
Top coat	$13.65-14.65	$14.15	400	400
Top quality latex paint (Ultra Deluxe 36-Series)				
Primer	$13.85-14.85	$14.35	350-400	350
Top coat	$18.35-19.35	$18.85	400	400
Premium quality latex paint (Plastic Kote 29-Series)				
Primer	$13.85-14.85	$14.35	350-400	350
Top coat	$19.25-20.25	$19.75	400	400
Low-emitting latex paint (Genesis 79-Series)				
Primer	$13.85-14.85	$14.35	350-400	350
Top coat	$20.40-21.40	$20.90	400	400

Using the values in Table E-3, the material cost for painting 70,000 ft^2 of wall area in the 20,000-ft^2 office building is as follows (assuming one coat of primer and one top coat and a 19.6% adder for sales tax, contractor bonds and insurance, profit and overhead, and general conditions, based on the Timberline model).

The material cost for the Pro Kote 23-Series is as follows:

Primer coat cost	=	((70,000 ft^2)/(400 ft^2/gal)) x $14.35/gal = $2511.25
Top coat cost	=	((70,000 ft^2)/(350 ft^2/gal)) x $14.15/gal = $2830
Total material cost	=	$2511.25 + $2830 = $5341.25
Full cost (inc. adder)	=	$5341.25 x 1.196 = **$6388.14**

Using the same calculation procedure, the full cost (inc. adder) for the other paints is as follows:

- Ultra Deluxe 36-Series: $7512.38
- Plastic Kote 29-Series: $7727.66
- Genesis 79-Series: $8002.74.

The differences between Genesis (the low-emitting paint) and the Pro Kote 23-Series are as follows. There is no difference per gallon for the primer. The difference per gallon for the top coat is $20.90 - $14.15 = $6.75 (Genesis is more expensive by $6.75 per gallon). The total first cost difference is $8002.74 - $6388.14 = $1614.60 or, by dividing by 20,000 ft^2 of building floor space, the difference in first cost is $80.73/1000 ft^2.

Using the same procedure, the other comparisons yield the following differences in first cost:

- Genesis compared with Ultra Deluxe 36-Series: $24.52/1000 ft^2
- Genesis compared with Plastic Kote 29-Series: $13.75/1000 ft^2.

Taking the highest and lowest per gallon differences and the total cost differential that considers the difference in coverage, the following summarizes this sustainable design feature:

- Sustainable design feature: low-emitting paint
- Incremental first cost ($/unit): -$3.19 to +$6.75
- Incremental cost ($/1000 ft^2): -$109.50 to +$101.66.

E.2 Documentation of Recycled Latex Paint

Based on cost estimates from the Timberline model, the 20,000-ft^2 office building has 70,000 ft^2 of interior painted surface. Recycled content primer was not available, so the cost comparisons below do not include primer costs. The data on typical contractor-grade paint gathered for the low-emitting latex paint options were used as the baseline for this comparison.

Recycled paint is post-consumer latex paint that has been sorted by type, color, and finish and reprocessed for resale. The U.S. Environmental Protection Agency (EPA) through the "Comprehensive Procurement Guideline"[2] encourages the purchase of latex paint made from post-consumer-recovered materials whenever the paint meets the project's specifications and performance requirements and is available and cost effective. The benefits of recycled paint for sustainable design typically include the following:

- Lower first cost (where the paint is available, it is typically offered at a lower price than virgin paint of a comparable quality)
- Reduced paint disposal needs (using the recycled paint creates a market for the excess paint often found after household and commercial construction projects)
- Decreased waste costs (recycling, rather than disposing of, the excess paint avoids waste disposal costs).

Two suppliers of recycled paint provided quotes for their products. These vendors sell recycled paint and accept excess latex paint for reprocessing and consolidation. Both vendors can ship their products to the Baltimore area. Shipping costs are not included in the cost summary below because the vendors noted that their distribution outlets are increasing and these charges may not be applicable over the long term. Also, both companies offered special rates for large projects and government buildings and under other special circumstances; those reduced rates were not considered for this evaluation.

[2] Available at URL: http://www.epa.gov/epg/products/paint.htm

Table E-4 lists the price and coverage data for each of the paint products and the values used in the calculations. The calculations assumed the midpoint of the price range and the lower end of the coverage range to offer a conservative comparison of the products.

Table E-4. Paint Prices and Coverage Rates

Paint Type	Price Range (per gal)	Price Assumed for the Calculations	Coverage (ft^2/gal)	Coverage Rate Assumed for the Calculations
Typical contractor latex paint				
Benjamin Moore SuperSpec	\$22.80-\$22.99	\$22.90	400-450	400
Sherwin Williams ProMar 400	\$10.50-12.50	\$11.50	350-400	350
Duron Pro Kote 23-Series	\$13.65-14.65	\$14.15	400	400
Recycled paint				
Nu-Blend Paints, Inc.	\$8.50 - \$10.60	\$9.55	350-400	350
E Coat	\$8.99 - \$11.99	\$10.49	250	250

Using the values in Table E-4, the material costs for painting 70,000 ft^2 of wall area in the 20,000-ft^2 office building are as follows (assuming one top coat and a 19.6% adder for sales tax, contractor bonds and insurance, profit and overhead, and general conditions based on the Timberline. model).

The material cost for Benjamin Moore SuperSpec is as follows:

Top coat cost = ((70,000 ft^2)/(400 ft^2/gal)) x \$22.90/gal = \$4007.50
Full cost (inc. adder) = \$4007.50 x 1.196 = **\$4792.97** (for top coat only)

Using the same procedure, the following are the full costs (inc. adder) for the other paints:

- Sherwin Williams ProMar 400: \$2750.80
- Duron Pro Kote 23-Series: \$3384.68
- Nu-Blend recycled paint: \$2284.36
- E Coat recycled paint: \$3499.50.

The differences between Nu-Blend recycled paint and the Benjamin Moore SuperSpec latex paint are as follows. The difference per gallon for the top coat is \$9.55 - \$22.90 = -\$13.35 (Nu-Blend is less expensive by \$13.35 per gallon). The total first cost difference is \$2284.36 - \$4792.97 = -\$2508.61 or, by dividing by 20,000 ft^2 of building floor space, the difference in first cost is -\$125.43/1000 ft^2.

Using the same procedure, the first cost differences between Nu-blend and the other latex paints are as follows:

- Nu-Blend compared with Sherwin Williams ProMar 400: -\$22.82/1000 ft^2
- Nu-Blend compared with Duron Pro Kote 23-Series: -\$55.02/1000 ft^2.

The differences between E Coat recycled paint and the three contractor-grade latex paints are as follows:

- E Coat compared with Benjamin Moore SuperSpec: -\$64.67/1000 ft^2
- E Coat compared with Sherwin Williams ProMar 40: \$37.44/1000 ft^2 (i.e., E Coat is more expensive by \$37.44/1000 ft^2)
- E Coat compared with Duron Pro Kote 23-Series: \$5.74/1000 ft^2 (E Coat is more expensive).

Taking the highest and lowest per gallon differences and the total cost differential that considers the difference in coverage, the following summarizes this sustainable design feature:

- Sustainable design feature: recycled paint
- Incremental first cost (\$/unit): -\$13.35 to -\$1.05
- Incremental cost (\$/1000 ft^2): -\$125.43 to +\$37.44.

E.3 Documentation of Costs of Concrete with Slag Content

Based on estimates provided by vendors, 250 yd^3 of 3000 pounds per square inch (psi) concrete would be needed for the 20,000-ft^2 office building. The baseline product is concrete made from 100% portland cement. The sustainable design option is concrete with a mix of portland cement and iron mill slag.

Blast furnaces producing iron from iron ore also produce a molten slag that at one time was considered a waste product. That slag can now be recycled into ground-granulated, blast-furnace slag cement by grinding the iron blast furnace slag to cement fineness.

NewCem, produced by Lafarge Corporation, was the product that the local vendors referenced when they provided price quotes. NewCem is manufactured locally/regionally at Sparrows Point, Maryland and therefore would contribute to local/regional material points in the Leadership in Energy and Environmental Design (LEED™) certification process. NewCem is a finely ground, granulated blast-furnace slag, manufactured from the byproduct of an iron blast furnace. It is made to meet the specification requirements of Grade 120 concrete, which ensures high uniform strengths. The specifications allow for the slag blend to be from 25% to 70% of the total cementitious materials.

Some of the benefits that have been noted for slag cement mixes include improved workability and pumpability for the unhardened concrete. For the hardened concrete, using slag content increases the 28-day strength, reduces permeability and heat of hydration, increases sulphate resistance, and controls the alkali silica reaction. During hot weather, slag concrete set times are lengthened; and during cold weather, the impact on set time had one of the local vendors stating that they did not use it during the winter.

Sales representatives at several Baltimore area vendors provided price quotes of ready-mix concrete. Table E-5 shows the ranges quoted by the vendor for the estimated retail price and shows the values used in the calculations. Note that not all the vendors that offered 100% portland cement concrete also offered concrete with slag content. The cost variances are due to the different vendors rather than product variations. In addition to vendor quotes, Lafarge Corporation, the manufacturer of the NewCem product being quoted by the vendors, was contacted. Lafarge explained that initially concrete made with the NewCem mix was much cheaper, but increases in product demand resulted in very little cost difference between 100% portland cement and NewCem/portland cement mixes. The purchase of slag content concrete depends on local availability. The prices will vary based on current demand and availability of the product.

Table E-5. Prices for Concrete

	Price Per	Price Range Assumed for the Calculations
100% portland cement concrete		\$63.95 - \$85
Quote 1	\$63.95	
Quote 2	\$85	
Quote 3	\$67.10	
Quote 4	\$78	
Quote 5	\$64.50	
Slag content		\$63.45 - \$85
Quote 1 (25% NewCem)	\$63.45	
Quote 2 (50% NewCem)	\$85	
Quote 3 (mix not specified)	\$67.10	

Using the values in Table E-5, the material costs for 250 yd^3 of concrete are as follows (assuming 19.6% adder for sales tax, contractor bonds and insurance, profit and overhead, and general conditions based on the Timberline model).

100% Portland Cement Concrete

Least expensive quote	=	250 yd^3 x \$63.95/ yd^3 = \$15,987.50
Cost including adder	=	\$15,987.50 x 1.196 = \$19,121.05
Most expensive quote	=	250 yd^3 x \$85/yd^3 = \$21,250
Cost including adder	=	\$21,250 x 1.196 = \$25,415
Price range	=	**\$19,121.05 to \$25,415**

Slag Content Concrete

Least expensive quote	=	250 yd^3 x \$63.45/yd^3 = \$15,862.50
Cost including adder	=	\$15,862.50 x 1.196 = \$18,971.55
Most expensive quote	=	250 yd^3 x \$85/yd^3 = \$21,250
Cost including adder	=	\$21,250 x 1.196 = \$25,415
Price range	=	**\$18,971.55 to \$25,415**

The differences between 100% portland cement and slag content cement are as follows. The difference per cubic yard of concrete ranges from \$63.95 – \$63.45 = -\$0.50 (concrete with slag content costing \$0.50 less than 100% portland cement concrete) to \$85 - \$85 = \$0 or no cost difference between the two products. The range of the total first cost difference is (\$19,121.05 - \$18,971.55) = -\$149.50 to (\$25,415 - 25,415) = \$0 or no cost difference. By dividing by 20,000 ft^2 of building floor space, the difference in first cost is -\$7.48/1000 ft^2 to \$0/1000 ft^2.

Taking the highest and lowest cost differences and the total cost differential, the following summarizes this sustainable design feature:

- Sustainable design feature: concrete with slag content
- Incremental first cost (\$/unit): -\$0.50 to \$0
- Incremental cost (\$/1000 ft^2): -\$7.48 to \$0.

E.4 Documentation of Costs of Concrete with Fly Ash Content

Based on estimates provided by vendors, 250 yd^3 of 3000 psi concrete would be needed for the 20,000-ft^2 office building. The baseline product is concrete made from 100% portland cement. The sustainable design option is concrete with a mix of portland cement and fly ash. Fly-ash-content concrete is not readily available in Baltimore; typically, it is only available on the West Coast. However, the summary in this section includes fly-ash-content cement to compare products and prices.

Concrete is traditionally made using 100% portland cement, aggregate, and water. Concrete made with portland cement has well-established mixing and setting properties and therefore does not require any extra instruction for use on a construction site. Concrete with fly ash means that some portion of the portland cement was replaced with fly ash. Fly ash was first used in the United States to reduce the quantity of portland cement needed for the Hoover Dam in 1929. Fly ash is a fine powder recovered from coal-fired electric power generation. Millions of tons of fly ash are produced every year by U.S. power plants. Two types of fly ash are generated in the U.S., Class C and Class F. Class C, produced from Western coal (low sulfur), is the one most typically used for structural concrete because it has a higher percentage of calcium oxide. Class F is produced from Eastern coal.[3]

Using concrete with fly ash content has the following qualitative benefits:

- Uses a waste product as a material, eliminating the fly ash from being sent to a landfill
- Requires less water
- Has lower embodied energy than portland cement material
- Is less likely to crack because it uses less water, decreasing replacement costs
- Is easier to use in cold weather than 100% portland cement
- Has workability advantages
- Offers water retention advantages
- Offers strength advantages depending on the recipe and set time
- Reduces the risk of expansion because of sulfate attack.

The following are some issues to consider when using fly-ash-content concrete:

- Smaller contractors may not be familiar with the product, potentially resulting in higher labor costs.
- Fly ash is generated at a variety of sources; therefore, the mineral makeup of the product is not 100% consistent, which could potentially result is quality control issues.
- If used as a complete replacement for portland cement, fly-ash content has issues related to freeze/thaw performance and a tendency to effloresce.
- Because of requirements in the Clean Air Act, some coal-fired electric power plants are generating a high-carbon fly ash that has to be reprocessed before it can be used as a replacement for portland cement. This could potentially result in less availability of fly ash in the future.

[3] May 7, 2002. ToolBase Services (see http://www.nahbrc.org/tertiaryR.asp?TrackID=&DocumentID=2072&CategoryID=72).

Table E-6 summarizes the costs for 100% portland cement concrete and concrete containing 20% fly ash as encouraged by the EPA's Affirmative Procurement Program. These costs are representative of cement walls and/or flooring for a 3000 psi mix delivered to the construction site.

Table E-6. Prices for Concrete

	Price Per Cubic Yard
100% portland cement concrete	$68.75
Fly ash content	$67.75

Only one price quote is offered to show as a comparison of fly ash costs vs. slag vs. 100% portland cement. The baseline price quote is from a West Coast vendor of ready-mix concrete. Several other vendors were contacted; and although they wouldn't provide a price quote, they stated that the 100% portland cement and 20% fly-ash-content concrete cost the same. All of the West Coast vendors contacted explained that initially concrete made with fly-ash content was much cheaper; but because of increases in demand for the product and changes in availability of quality fly ash, very little cost difference exists between 100% portland cement and fly ash/portland cement mixes. The purchase of fly-ash-content concrete depends on local availability. The prices will vary based on current demand and availability of the product.

Using the values in Table E-6, the material costs for 250 yd^3 of concrete are as follows (assuming 19.6% adder for sales tax, contractor bonds and insurance, profit and overhead, and general conditions based on the Timberline model).

100% Portland Cement Concrete

Concrete cost = 250 yd^3 x \$68.75/yd^3 = \$17,187.50
Cost including adder = \$17,187.50 x 1.196 = **\$20,556.25**

20% Fly-Ash-Content Concrete

Least expensive quote = 250 yd^3 x \$67.75/yd^3 = \$16,937.50
Cost including adder = \$16,937.50 x 1.196 = **\$20,257.25**

The differences between 100% portland cement and 20% fly-ash-content cement are as follows. The difference per cubic yard of concrete ranges from \$67.75 to \$68.75 = -\$1.00 (concrete with fly ash content costs \$1 less than 100% portland cement concrete). The range of the total first cost difference is \$20,257.25 - \$20,556.25 = -\$299. By dividing by 20,000 ft^2 of building floor space, the difference in first cost is -\$14.95/1000 ft^2.

Taking the highest and lowest cost differences and the total cost differential, the following summarizes this sustainable design feature:

- Sustainable design feature: concrete with fly ash
- Incremental first cost (\$/unit): -\$1.00
- Incremental cost (\$/1000 ft^2): -\$14.95

E.5 Documentation of Costs of Carpet with Recycled Content

Based on cost estimates from the Timberline model, the 20,000-ft^2 office building has 2,000 yd^2 of interior carpet. A range of environmentally preferable carpet products is currently available on the carpet market. Product examples include refurbished used carpet and new carpet made from old carpet and carpet scraps, carpet backing, auto parts, soda bottles, and flooring materials. For this study a simple comparison was conducted of carpet made from 100% virgin material versus carpet with recycled content. The percentage of recycled content and the source of the recycled content are not specified for this comparison because the products of similar quality vary so dramatically in design, but the costs do not vary as significantly. The EPA, through the "Comprehensive Procurement Guideline," encourages the purchase of carpet with recycled content when it is available, doesn't compromise quality, and is cost effective.

Eight national and Baltimore area carpet vendors were contacted for prices on products. Only two of the vendors provided a complete set of prices for different carpet styles. The installation prices include the cost of adhesives.

C&A Floorcoverings' Habitat and Ecotone products are both solution-dyed nylon, which is fade resistant and has the same maintenance requirements as typical carpet. Both of these products are about 82% recycled content by weight. Explorer, Expedition, and Wayfarer carpets are typical contractor-grade carpets that are also solution-dyed and are manufactured with 100% new face yarn and a recycled backing (resulting in about 31% recycled content by weight). Product pricing for products made with 100% virgin materials was not available because all of C&A Floorcoverings' carpet backing has recycled content.

The sales representative at the Carpet Fair Commercial Division was not aware of any products made with recycled content and therefore only offered quotes for carpets with virgin material. The sales representative at Dupont Flooring Systems stated that the product cost differences are the result of performance requirements, patterns, color, etc., rather than whether a product has recycled content.

Mohawk Commercial Carpet produces a wide variety of both recycled content and virgin content carpets. Their recycled content carpets are made of nylon that can be recycled into carpet again, and the products that were discussed also are made with nonlatex-based backing. The sales representative provided prices for both patterned and nonpatterned solution-dyed carpets, which are fade resistant. The sales representative said that the general rule of thumb for Mohawk carpets is that equivalent quality carpet made of virgin materials usually costs about \$1/yd^2 more than the recycled content carpet. Maintenance requirements for the recycled content versus virgin content carpet do not differ.

Table E-7 lists the price of carpet made from virgin materials and from recycled materials. The calculations assumed the midpoint of the price range to offer a conservative comparison of the products.

Table E-7. Prices for Recycled Content and Virgin Carpet

Carpet Type	Price Per Square Yard	Price Per Square Yard Installed	Price Assumed for the Calculations	Percentage Recycled Content
C&A Floorcoverings				
Habitat	$18.80	$28.80-$30.80	$29.80	82%
Ecotone	$19.95	$29.95-$31.95	$30.95	82%
Explorer	$22.00	$32.00-$34.00	$33.00	31%
Expedition	$24.00	$34.00-$36.00	$35.00	31%
Wayfarer	$26.00	$36.00	$36.00	31%
Carpet Fair Commercial Division				
Broadloom 100% virgin nylon carpet	NA*	$18.00-$20.00	$19.00	0%
Virgin carpet tiles	NA	$23.00-$26.00	$24.50	0%
Dupont Flooring Systems				
Recycled content face yarn and backing	NA	$35.00	$35.00	30-80%
Carpet made with virgin materials	NA	$35.00	$35.00	0%
Mohawk Commercial Carpet				
Performer 28 (no pattern)	$12.00-$16.00	$18.00-$22.00	$20.00	0%
Collegiate (no pattern, budget carpet)	$6.00-$10.00	$14.00-$18.00	$16.00	0%
Surreal (no pattern)	$12.00-$16.00	$18.00-$22.00	$20.00	50%
Virgin patterned carpet	$18.00-$22.00	$24-$28	$26.00	0%
Graphic Edge (pattern)	$12.00-$16.00	$18.00-$22.00	$20.00	50%
Maritage Collection (4 to 5 products with pattern)	$17.00-$21.00	$23.00-$27.00	$25.00	50%
Tracks (pattern)	$13.00-$17.00	$19.00-$23.00	$21.00	50%
Feathergrid (pattern)	$13.00-$17.00	$19.00-$23.00	$21.00	50%
Structures (pattern)	$13.00-$17.00	$19.00-$23.00	$21.00	50%
* NA = not available.				

Using the values in Table E-7, the material costs for carpeting 2000 yd^2 of floor space in the 20,000-ft^2 office building are as follows (assuming 19.6% adder for sales tax, contractor bonds and insurance, profit and overhead, and general conditions based on the Timberline model) with Habitat carpet:

Product cost = 2000 yd^2 x \$29.80/yd^2 = \$59,600
Full cost (inc. adder) = \$59,600 x 1.196 = \$71,282

Using the same calculation procedure, the full costs (inc. adder) for the other products are as follows:

• Ecotone	$74,032
• Explorer	$78,936
• Expedition	$83,720
• Wayfarer	$86,112
• Broadloom 100% virgin nylon carpet	$45,448
• 100% virgin carpet tiles	$58,604
• Recycled content face yarn and backing	$83,720
• Carpet made with 100% virgin materials	$83,720
• Performer 28 (no pattern)	$47,840
• Collegiate (no pattern, budget)	$38,272
• Surreal (no pattern)	$47,840
• Virgin patterned carpet	$62,192
• Graphic Edge (pattern)	$47,840
• Maritage Collection (4 to 5 products, pattern)	$59,800
• Tracks, Feathergrid, and Structures (pattern)	$50,232.

The difference between Habitat and the 100% virgin carpet (broadloom) is as follows. The difference per square foot for the installed carpet is $29.80 - $19 = $10.80. The total first cost difference is $71,281.60 - $45,448 = $25,833.60 or, by dividing by 20,000 ft^2 of building floor space, the difference in first cost is $1291.68/1000 ft^2.

Using the same calculation procedure, a comparison of the first cost of Habitat to the others is as follows:

- Habitat compared with 100% virgin carpet tiles: $633.88/1000 ft^2
- Habitat compared with carpet made with 100% virgin materials: -$621.92/1000 ft^2
- Habitat compared with Performer 28: $1172.08/1000 ft^2
- Habitat compared with Collegiate (budget): $1650.48/1000 ft^2
- Habitat compared with virgin patterned carpet: $454.48/1000 ft^2.

The differences between Ecotone and the 100% virgin carpets are as follows:

- Ecotone compared with broadloom 100% virgin nylon carpet: $1429.22 per 1000 ft^2
- Ecotone compared with 100% virgin carpet tiles: $771.42/1000 ft^2
- Ecotone compared with carpet made with 100% virgin materials: -$484.38/1000 ft^2
- Ecotone compared with Performer 28: $1309.62/1000 ft^2
- Ecotone compared with Collegiate (budget): $1778.02/1000 ft^2
- Ecotone compared with virgin patterned carpet: $592.02/1000 ft^2.

The differences between Explorer and the 100% virgin carpet products are as follows:

- Explorer compared with broadloom 100% virgin nylon carpet: $1674.40/1000 ft^2
- Explorer compared with 100% virgin carpet tiles: $1016.60/1000 ft^2
- Explorer compared with carpet made with 100% virgin materials: -$239.20/1000 ft^2
- Explorer compared with Performer 28: $1554.80/1000 ft^2

- Explorer Compared with Collegiate (budget): $2033.20/1000 ft^2$
- Explorer Compared with virgin patterned carpet: $837.20/1000 ft^2$.

The differences between Expedition and the 100% virgin carpet products are as follows:

- Expedition compared with broadloom 100% virgin nylon carpet: $1913.60/1000 ft^2$
- Expedition compared with 100% virgin carpet tiles: $1255.80/1000 ft^2$
- Expedition compared with carpet made with 100% virgin materials: $0/1000 ft^2$
- Expedition compared with Performer 28: $1794.00/1000 ft^2$
- Expedition compared with Collegiate (budget): $2272.40/1000 ft^2$
- Expedition compared with virgin patterned carpet: $1076.40/1000 ft^2$.

The differences between Wayfarer and the 100% virgin carpet products are as follows:

- Wayfarer compared with broadloom 100% virgin nylon carpet: $2033.20/1000 ft^2$
- Wayfarer compared with 100% virgin carpet tiles: $1375.40/1000 ft^2$
- Wayfarer compared with carpet made with 100% virgin materials: $119.60/1000 ft^2$
- Wayfarer compared with Performer 28: $1913.60/1000 ft^2$
- Wayfarer compared with Collegiate (budget): $2392.00/1000 ft^2$
- Wayfarer compared with virgin patterned carpet: $1197.50/1000 ft^2$.

The differences between recycled content face yarn and backing and the 100% virgin carpet products are as follows:

- Recycled content face yarn and backing compared with broadloom 100% virgin nylon carpet: $1913.60/1000 ft^2$
- Recycled content face yarn and backing compared with 100% virgin carpet tiles: $1255.80/1000 ft^2$
- Recycled content face yarn and backing compared with carpet made with 100% virgin materials: $0/1000 ft^2$
- Recycled content face yarn and backing compared with Performer 28: $1794.00/1000 ft^2$
- Recycled content face yarn and backing compared with Collegiate (budget): $2272.40/1000 ft^2$
- Recycled content face yarn and backing compared with virgin patterned: $1076.40/1000 ft^2$.

The differences between Surreal and the 100% virgin carpet products are as follows:

- Surreal compared with broadloom 100% virgin nylon carpet: $119.60/1000 ft^2$
- Surreal compared with 100% virgin carpet tiles: -$538.20/1000 ft^2$
- Surreal compared with carpet made with 100% virgin materials: -$1794.00/1000 ft^2$
- Surreal compared with Performer 28: $0/1000 ft^2$
- Surreal compared with Collegiate (budget): $478.40/1000 ft^2$
- Surreal compared with virgin patterned carpet: -$717.60/1000 ft^2$.

The differences between Graphic Edge and the 100% virgin carpet products are as follows:

- Graphic Edge compared with broadloom 100% virgin nylon carpet: $119.60/1000 ft^2$
- Graphic Edge compared with 100% virgin carpet tiles: -$538.20/1000 ft^2$
- Graphic Edge compared with carpet made with 100% virgin materials: -$1794.00/1000 ft^2$
- Graphic Edge compared with Performer 28: $0/1000 ft^2$

- Graphic Edge compared with Collegiate (budget): $478.40/1000 ft^2
- Graphic Edge compared with virgin patterned carpet: -$717.60/1000 ft^2.

The differences between the Maritage Collection and the 100% virgin carpet products are as follows:

- Maritage Collection compared with broadloom 100% virgin nylon carpet: $717.60/1000 ft^2
- Maritage Collection compared with 100% virgin carpet tiles: $59.80/1000 ft^2
- Maritage Collection compared with carpet made with 100% virgin materials: -$1196.00/1000 ft^2
- Maritage Collection compared with Performer 28: $598.00/1000 ft^2
- Maritage Collection compared with Collegiate (budget): $1076.40/1000 ft^2
- Maritage Collection compared with virgin patterned carpet: -$119.60/1000 ft^2.

The differences between Tracks, Feathergrid, and Structures and the 100% virgin carpet products are as follows:

- Tracks, Feathergrid, and Structures compared with broadloom 100% virgin nylon carpet: $239.20/1000 ft^2
- Tracks, Feathergrid, and Structures compared with 100% virgin carpet tiles: -$418.60/1000 ft^2
- Tracks, Feathergrid, and Structures compared with carpet made with 100% virgin materials: -$1674.40/1000 ft^2
- Tracks, Feathergrid, and Structures compared with Performer 28: $119.60/1000 ft^2
- Tracks, Feathergrid, and Structures compared with Collegiate (budget): $598.00/1000 ft^2
- Tracks, Feathergrid, and Structures compared with virgin patterned carpet: -$598.00/1000 ft^2.

Taking the highest and lowest per square yard differences and the total cost differential, the following summarizes this sustainable design feature:

- Sustainable design feature: recycled content carpet
- Incremental first cost ($/yd): -$15 to +$20
- Incremental cost ($/1000 ft^2): -$1794.00 to +$2392.00.

E.6 Documentation of Costs of Certified Wood Options

The following baseline materials would be replaced with certified wood products:

- 72 wood doors: 3 ft x 6 ft, 8 in. x 1 ¾ in. 5-ply particle core with birch faces (stained)
- 3060 linear feet of vinyl baseboard trim.

A certified wood product is a product that originates from a forest that has been certified as well managed. Typically, certified wood products are labeled by one of the organizations that set the standards for responsible forest management. There are two international certified wood product standards organizations – Forest Stewardship Council and the International Standards Organization – and four North American organizations – American Tree Farm System, Canadian Standards Association International, Forest Stewardship Council, and Sustainable Forestry Initiative.

Certification provides an independent assurance that a forestry operation meets the standards set by the certification organization. The standards look for environmentally, socially, and economically responsible management practices that ensure the long-term health and productivity of forests for timber production, wildlife habitat, water quality, and community employment.

Acquiring cost-competitive certified wood products for a construction project might require considerable lead-time depending on the product. To acquire the quotes provided in Table E-8 (cost of doors) and Table E-9 (cost of baseboard trim), local vendors of doors and baseboard were asked about the baseline product as well as certified wood products. Most of the vendors who sell typical contractor-grade products were not able to provide accurate information about certified wood products.

Table E-8. Costs of Doors

		Product Description
Certified wood doors		
Quote 1	$192-$200	Particle board core
Quote 2	$168-$176	Particle board core
Quote 3	$175-200	Particle board core
Quote 4	$250-$300	Solid pine
Quote 5	$400	Solid hardwood
Traditional wood doors		
Quote 1	$160	Particle board core
Quote 2	$160	Particle board core
Quote 3	$165	Particle board core
Quote 4	$372	Solid birch
Quote 5	$300-400	Solid birch

The Sustainable Forest Products Resource ForestWorld Marketplace[4] and the Certified Forest Products Council[5] were the easiest sources of information regarding available certified wood products. The certified wood products vendors stated that the price and quality of certified wood products depended dramatically on how much time they have to locate the desired product.

Note that the baseline for the building assumes particle core doors. If certified wood particle core doors replace the baseline doors, it is possible that action would not meet the LEED requirements for getting a certified wood credit. The particle core doors are made with a very small quantity of certified wood (5% to 10% of the door); most of the door is made from recycled content. Therefore, solid wood doors were also considered in this analysis.

Using the range of values in Table E-8 and E-9 (excluding the data for the solid mahogany doors), the material cost for replacing 72 contractor-grade 3 ft x 7 ft x 1 ¾ in. 5-ply particle core door with birch faces with certified wood products is as follows (assuming 19.6% adder for sales tax, contractor bonds and insurance, profit and overhead, and general conditions based on the Timberline model).

[4] Available at http://www.forestworld.com.
[5] Available at http://www.certifiedwood.org.

Table E-9. Baseboard Trim

Trim Type	Price Per Linear Foot	Product Description
Certified wood baseboard trim		
Quote 1	$1.50	Ash
Quote 2	$1.13	Willow
Quote 3	$1.59	Oak
Vinyl trim		
Quote 1	$0.356	Black
Quote 2	$0.383	Brown
Quote 3	$0.407	Off-white
Quote 4	$2.50	Polyurethane molding
Quote 5	$0.82	Rubber back
Quote 6	$0.80-$1	Vinyl trim installed
Quote 7	$1-1.2	Vinyl-rubber blend installed
Wood trim		
Quote 1	$0.49	Ranch pine
Quote 2	$1.18	Wood molding

The material cost for the contractor-grade 5-ply particle core door is as follows:

Product cost = 72 doors x $160 to $165/door = $11,520 to $11,880
Full cost (inc. adder) = $11,520 to $11,880 x 1.196 = $13,778 to $14,208

Using the same approach, the full cost ranges (inc. adder) of the other products are as follows:

- Certified wood particle core door: $14,467 to $17,222
- Contractor-grade solid door: $25,834 to $34,445
- Certified solid wood door: $21,528 to $34,445.

The differences between the contractor-grade particle core door and the certified wood products are as follows.

Contractor-Grade 5-ply Particle Core Door Compared with Certified Wood Particle Core Door
The difference per door is ($160 to $165/door) - ($168 to $200/door) = -$8 to $40/door. The total first cost difference is ($13,778 to $14,208) - ($14,467 to $17,222) = $259 to $3444, or by dividing by 20,000 ft^2 of building floor space, the difference in first cost ranges from $12.95 to $172.20/1000 ft^2.

Solid Wood Door Compared with Certified Solid Wood Door
The difference per door is ($300 to 400/door) - ($250 to $400/door) = -$150 to $100/door. The total first cost difference is ($25,834 to $34,445) - ($21,528 to $34,445) = -$12,917 to $8611, or by dividing by 20,000 ft^2 of building floor space, the difference in first cost ranges from -$645.85 to $430.55/1000 ft^2.

Taking the highest and lowest differences and the total cost differential, Table E-10 summaries this sustainable design feature.

Table E-10. Summary of Certified Wood Options

Sustainable Design Feature	Incremental First Cost ($ per unit)	Incremental Cost ($/1000 ft^2)
Certified wood particle core door vs. contractor-grade particle core door	$3 to $40	$12.95 to $172.20
Certified wood solid wood door vs. solid wood door	-$150 to $100	-$645.85 to $430.55

The assumed baseline material is 3060 linear feet of vinyl baseboard trim with alternative certified wood products being solid ash, willow, and oak baseboard trim. The differences in product quality, appearance, and durability have not been included in the cost comparisons. Noncertified wood trim first costs were also gathered to offer a more equivalent comparison from a product quality perspective.

Using the range of values in Table E-9 (excluding quotes 4 through 7 because they offer higher-end products or included installation costs), the material cost for replacing 3060 linear feet of vinyl baseboard trim with certified wood products is as follows (assuming 19.6% adder for sales tax, contractor bonds and insurance, profit and overhead, and general conditions based on the Timberline model).

The material cost for the contractor-grade vinyl baseboard trim is as follows:

Product cost = 3060 linear feet x $0.356 to $0.407/linear foot = $1089 to $1245
Full cost (inc. adder) = $1089 to $1245 x 1.196 = $1302 to $1489

Using the same calculation approach, the full costs (inc. adder) for the other products are as follows:

- Contractor-grade wood baseboard trim: $1793 to $4319
- Certified wood baseboard trim: $4136 to $5819.

The difference between the contractor-grade vinyl baseboard trim and the certified wood baseboard trim is as follows. The difference per linear foot of vinyl trim is ($0.356 to $0.407/linear foot) - ($1.13 to $1.59/linear foot) = $0.72 to $1.23/linear foot. The total first cost difference is ($1302 to $1489) - ($4136 to $5819) = $2647 to $4517, or by dividing by 20,000 ft^2 of building floor space, the difference in first cost ranges from $132.35 to $225.85/1000 ft^2.

The comparison between the contractor-grade solid wood baseboard trim and the certified wood baseboard trim yields a range of -$9.15 to $201.30/1000 ft^2.

Appendix F: Detailed Discussion of Research Studies on Occupant Health, Comfort, and Productivity[1]

This appendix provides details on the studies reviewed for Section 2.6 ("Lower Absenteeism and Improved Productivity") and Section 3 ("The Social Benefits of Sustainable Design"). The studies deal with indoor air quality (Section F.1) and other sustainable design practices (Section F.2).

F.1 Indoor Air Quality

This section describes the studies reviewed on increased ventilation effectiveness, low-emitting materials, indoor chemical and pollutant source control, controllability of systems, thermal conditions, daylight and views, and potential problems with daylight and windows.

F.1.1 Increased Ventilation Effectiveness

Increased ventilation effectiveness includes strategies such as natural ventilation, increased air change rate, increased volume of outdoor air, and increased air filtration. The health benefits, productivity benefits, and comfort and satisfaction of such strategies are discussed below.

Health Benefits

Many large-scale building studies show that increased volumes of outdoor air, natural ventilation, air ventilation rates, and filtration of air and improved cleaning and maintenance of systems are correlated with reduced sick building syndrome (SBS) symptoms as well as reduced allergy and asthma symptoms and transmission of infections diseases (Brightman and Moss 2000; Fisk 2001). Most of the studies cited in the literature are surveys and do not include information on how frequently windows are opened by the workers in naturally ventilated buildings. Therefore, it is not known whether positive impacts are due to psychological factors (e.g., control) or to actual increases in fresh air. Further, in areas where outdoor air has high levels of pollutants or allergens, indoor air quality may actually be compromised. For instance, a study in Norway found that nurses experienced more eye irritation in hospitals near roads with heavy traffic because of the increased dust settlement rates (Smedbold et al. 2001).

A controlled field experiment by Wargocki et al. (2000) in Denmark found that increasing ventilation rates beyond minimum levels prescribed in standards is associated with reduced symptoms. Three outdoor air change rates were studied: 0.6, 2, or 6 air changes (AC)/hr (corresponding to 3, 10, or 30 liters (L)/person/hr). Temperature and humidity were kept constant at 72ºF and 40% relative humidity. The researchers found that the workers felt better and had fewer symptoms as ventilation rates increased. The workers also perceived the air as fresher.

A study of 3720 employees in 40 buildings also found reduced symptoms and lower absenteeism in buildings with higher ventilation rates (Milton et al. 2000). The "high" ventilation rate was about 50 cubic feet per minute (cfm)/person outdoor air compared with a "moderate" rate of 25 cfm/person. (This corresponds to 12 L/person/hr and 24 L/person/hr; these data are very consistent with the Wargocki et al. [2000] study.) Milton et al. (2000) estimated the cost of sick leave as $480/person/yr.

[1] This appendix was written by J. Heerwagen, Pacific Northwest National Laboratory.

Productivity Benefits

Performance assessments in work settings are rare because of the difficulty of capturing actual performance measures and linking them to specific environmental features. Nonetheless, a field experiment in Denmark shows that workers performed better on a typing task and perceived themselves as able to think more clearly with increased ventilation (Wargocki et al. 2000). A field experiment by Nunes et al. (1993) looked at the link between SBS symptoms associated with ventilation rates and work performance. They found that workers reporting SBS symptoms worked 7.2% more slowly on a vigilance task and made 30% more errors on a numerical task.

Other studies have assessed self-ratings of productivity. Based on a study of 40 buildings in the United Kingdom, occupants in naturally ventilated or mixed-mode buildings rated their perceived productivity significantly higher than occupants of air-conditioned buildings (Leaman and Bordass 2001). Similar results were found in a study by Rowe et al. in Australia where workers in mixed-mode buildings rated their work performance higher (cited in Leaman and Bordass 2001).

Comfort and Satisfaction

Workers prefer spaces with operable windows compared with completely mechanically ventilated and conditioned spaces, except in hot summer weather (Leaman and Bordass 2001). In the Wargocki et al. (2000) study cited above, workers were more satisfied with the air quality and rated the air as fresher with increased ventilation, from 0.6 AC/hr to 6 AC/hr.

F.1.2 Low-Emitting Materials

The vast majority of research on materials emissions has been conducted in specialized facilities and cannot be generalized to office environments. However, as discussed below, some field studies provide data on occupant health and productivity benefits.

Health Benefits

Brightman and Moss (2001), in a review of large-scale studies of SBS in Europe and the United States, identify carpet as a key risk factor in SBS. Other building factors that show mixed findings (some show increases in symptoms, others do not) are total volatile organic compounds (VOCs), fleecy materials, and formaldehyde. (Work and personal factors affecting symptom occurrence include stress, history of allergy, high use of photocopy machines, and high level of paper work.) A field intervention by Pejtersen et al. (2001) compared symptoms in a newly renovated area of a building with a control group who did not experience the renovation. The upgrades included renovating the HVAC system and replacing the carpet with a low-emitting vinyl floor material. The researchers found significantly improved perceptions and reduced illness symptoms in the renovated space. It is not known, however, to what extent the improvements were due to the HVAC system or to changes in the floor materials.

Productivity Benefits

A field simulation study testing the effects of a 25-year-old carpet on work performance found that when the carpet was absent, performance increased on a variety of clerical as well as complex cognitive tasks requiring mental effort and high attention, including logical thinking, arithmetic, and vigilance (Wargocki et al. 2000). The authors attribute this to airborne particulates, although the exact mechanisms by which particulates might affect cognitive functioning are not discussed.

F.1.3 Indoor Chemical and Pollutant Source Control

Relatively little work has been done on controlling indoor chemicals and pollutant sources. No studies were found on productivity or comfort, and only two studies on health impacts were found. For instance, a Danish experimental office study found an increase in eye and skin irritations in an office with computers, laser printers, and a photocopier than an office without the technologies. The office with the equipment was found to have higher levels of ozone, respirable particulates, and VOCs (Wolkoff et al. 1992). Brown (1999) also found that emissions from dry-process photocopiers increased when temperatures increased from 73ºF to 90ºC and that particle emissions occurred when the copier was idle and copying. Numerous other studies, cited in Hedge (2000), noted that SBS problems increase for workers with high computer use.

F.1.4 Controllability of Systems

A growing body of literature in building science and health care underscores the psychological, functional, and health benefits of having some degree of control over the physical environment, including ventilation, temperatures, lighting, and privacy. The health benefits, productivity benefits, and comfort and satisfaction from such controls are discussed below.

Health Benefits

A field study of an air filtration system integrated into the office furniture system at the breathing zone in a Canadian government building found lower levels of symptoms and reduced absenteeism rates compared with a control floor that did not have the system (Hedge et al. 1993).

A study of 11,000 workers in the Netherlands by Preller et al. (1990) found that absenteeism due to SBS is likely to be 34% lower when workers have control over their thermal conditions. A field study of a furniture-integrated breathing zone system in a Canadian government office building found reduced absenteeism and lower levels of symptoms than a control floor in the same building without the system (Hedge et al. 1993).

Productivity Benefits

Studies have documented increases in work performance on various tasks when occupants have some degree of control over temperature and/or ventilation conditions at their workstations (Kroner et al. 1992; Wyon 1996). Kroner et al. (1992) used organizational performance data to assess the impact of personal control over temperature and ventilation at the workstation level and concluded that the control system increased productivity by 3%.

Drawing on a review of research on indoor air quality and thermal conditions, Wyon (1996) estimated that providing workers with temperature control of just three degrees (plus or minus) would result in performance increases of 7% for typical clerical tasks, 2.7% for logical thinking tasks, 3% for skilled manual work, and 8.6% for very rapid manual work.

A large-scale office study in England also shows that personal control over the environment (as measured by a summary of ratings of perceived control over lighting, noise, temperatures, and ventilation) was one of four key factors affecting occupants' perceived productivity at work (Leaman and Bordass 2001). Of these controls, the most important was control over noise and the least important was control over lighting. The authors also conclude that personal control is less important to workers when ambient conditions are comfortable and when building managers respond promptly to discomfort complaints.

Comfort and Satisfaction

There is evidence that people are more tolerant of conditions the more control opportunities they have, regardless of whether they choose to use the control (Leaman and Bordass 2001). Overall comfort and satisfaction also increases with personal control over ventilation and temperatures (Kroner et al. 1992; Brager and deDear 2000).

F.1.5 Thermal Conditions

The literature on thermal comfort in buildings is voluminous (for instance, see deDear et al. 1993). No attempt is made here to provide a detailed review of this research, much of which focuses on comfort. Key findings from the literature show the following:

- Thermal discomfort is common in buildings.
- Temperature conditions influence symptoms associated with SBS.
- Performance impacts of thermal conditions depend on the nature of the tasks as well as on personal factors.

The health benefits, productivity benefits, and comfort and satisfaction from thermal conditions in buildings are discussed below.

Health Benefits

Elevated temperatures are associated with increases in illness symptoms (Wyon 1996, 2000). As researchers systematically increased indoor temperatures from 68°F to 76.2°F, they found increased incidents of headache and other SBS symptoms. Wyon (1996) also reports increased incidence of headache and fatigue as indoor temperatures increase from 68°F to 76°F. At 76°F, 60% of the workers experienced headache compared with 10% at 68°F.

An extensive review of the epidemiological literature found that "dampness" (a thermal comfort factor) in buildings increases the risks of respiratory symptoms (cough, wheezing, and asthma) as well as other symptoms such as tiredness, headache, and respiratory infections (Bornehag et al. 2001). Unfortunately, the study's data are from worker surveys and do not include actual moisture levels or sources of the problem.

Performance Benefits

Although discomfort is believed to negatively affect productivity, the relationship is complex and is related to the nature of the work itself, time of day, and personal factors such as pre-existing medical conditions (Wyon 1996, 2000). For instance, performance on creative and memory tasks is higher when temperatures are slightly elevated. However, performance decreases on tasks requiring concentration and logical thinking tasks when temperatures are slightly elevated. Performance on these types of tasks is better when temperatures are slightly cool.

Comfort and Satisfaction

Numerous studies in the United States and elsewhere have consistently shown high levels of dissatisfaction and high variability in comfort for any given thermal condition (Heerwagen and Diamond 1992; Leaman and Bordass 2001). Given the high range of variability in comfort, the ability to control temperatures and ventilation at the workstation level may be the single most effective way of increasing thermal comfort (Wyon 1996).

In a study of the costs of dealing with discomforts, Federspiel (2000) estimates that efforts to increase comfort could result in a 12% decrease in labor costs of responding to complaints. His data show that it takes 1.4 hours on average to diagnose a hot complaint and 1.7 hours to diagnose a cold complaint. His data also suggest that complaints are not due to differences among individuals, but rather to HVAC faults or poor control performance.

F.1.6 Daylight and Views

It has long been known that people prefer to be in spaces with windows and daylight (Collins 1975). However, it is only recently that researchers have begun to investigate the health and productivity impacts of daylight and views. The following summarizes the research on daylight and views:

- Daylight and sun penetration may have positive benefits on health.
- The benefits of views depend to a large extent on the view itself (e.g., degree of naturalness and distance of the view).
- Although there is little evidence for direct impacts on work performance, window views have been found to influence a number of mental processes that are associated with performance on complex cognitive tasks.

The health benefits, productivity benefits, and comfort and satisfaction from daylight and views in buildings are discussed below.

Health Benefits

A field study of lighting conditions in a government office building in England found that headache incidence decreased significantly with increased access to daylight (Wilkins et al. 1989). People who suffer from Seasonal Affective Disorder (SAD) may also benefit from access to daylight. Because people with SAD prefer more brightly lighted spaces than people who do not suffer from seasonal variation in mood and well-being, being adjacent to a window where light levels are higher than interior spaces may have therapeutic effects (Heerwagen 1990). Although daylight design generally tries to reduce or eliminate the penetration of direct sunlight into buildings, a modest level of sunlight (sun "spots") may be beneficial to health and well-being.

Two studies are cited in a report prepared by Johns Hopkins researchers on the connection between the built environment and patient outcomes (Rubin et al. 1998). One study compared the length of stay for 174 patients with depression who were randomly assigned to a "sunny" or dull hospital room (Beauchemin and Hays 1996). Those in the sunny rooms stayed an average of 16.9 days compared with 19.5 days for patients in the rooms without sun. The results held true regardless of season. Another healthcare study cited in the Johns Hopkins report found that differences in exposure to natural sunlight affected the serum OH-D concentrations in long-term geriatric patients (Lamberg-Allardt 1984). There is also reason to believe that access to high daylight levels and sunlight for at least part of the day would be beneficial to persons suffering from SAD (Heerwagen 1990). Daylight and sunlight "patches" indoors have been found also to enhance emotional functioning, as long as the sunlight does not increase glare or temperature discomfort (Boubekri et al. 1991; Leather et al. 1998).

Physical benefits of windows and views (especially views of nature) include stress reduction and recovery from illness. In a study of patients recovering from hospital surgery, Ulrich (1984) found that those who had a view of a natural landscape recovered faster and spent fewer days in the hospital than matched control patients who viewed an adjacent wing of the hospital. Although similar studies have not been conducted in work settings, other research cited above clearly indicates that nature views have positive impacts on stress recovery. In a field study of office workers, Kaplan (1992) found that workers with window views of nature felt less frustrated and more patient and reported more overall life satisfaction and better health than workers who did not have visual access to the outdoors or whose view consisted of built elements only. When deprived of windows, people report more negative moods and a loss of contact with the outdoor world, especially loss of connection to time and weather (Collins 1975; Heerwagen and Orians 1986).

Productivity Benefits

The only current data available on the impact of daylight and views on performance are from a large-scale study of the link between daylight design and test performance in schools (Heschong-Mahone Group 1999). The study found that children scored higher on test scores in schools with the best daylight design. However, many other building factors may have influenced these outcomes. Thus, the results should be taken as preliminary until additional research support is found.

Studies of window views show that people perform better on tasks requiring focused attention (such as proofreading) when they have views of nature compared with views of buildings or windowless conditions (Hartig et al. 1991). Window views may be especially effective in providing micro rest breaks of a few minutes or less. Micro rest breaks have positive impacts on performance and attention (Zijlstra et al. 1999).

Although full spectrum electric light is widely believed to have benefits similar to daylight, no scientific evidence exists for this claim. A major review of the research in this area by Veitch and McColl (1994) found no indications that full spectrum fluorescent lighting was associated with any increases in psychological well-being, health, or productivity.

Comfort and Satisfaction

Numerous office studies in the United States, England, and Europe have found increased satisfaction levels with increases in daylight (Collins 1975; Heerwagen and Diamond 1991; Leaman and Bordass 2001). Although most research on windows has focused on views, the size and location of windows also matters. A series of studies by Butler and Biner (1989) shows that the preferred size, shape, and location of windows are functions of the specific space under consideration. People prefer larger windows in settings for relaxation and smaller windows in settings where privacy is desired (e.g., bedrooms and bathrooms).

F.1.7 Potential Problems with Daylight and Windows

Although windows and daylight have numerous benefits, as identified above, they also have the potential to create discomfort and distractions when not properly designed. Office studies in the United States and elsewhere have consistently found that workers are bothered by glare from windows, and this is especially problematic for computer work. These problems are resolved to a great extent using flat screen computers and indirect lighting (Hedge et al. 1995). The absence of sunlight controls also increases the potential for heat stress. Heat reflective glazing and shading devices do not fully resolve these difficulties (Heerwagen and Diamond 1991; Leaman and Bordass 2001). Furthermore, for facilities with 24-hour operation schedules, the lack of daylight and views may lead to feelings of inequitable distribution of amenities among night-time workers who do not have the same access to daylight and views (Heerwagen and Wise 1998).

F.2 Other Sustainable Design Practices

Although interior design strategies are not included in the current version of the Leadership in Energy and Environmental Design (LEED™) rating system, practitioners are beginning to specify more open plan environments as a way to reduce materials, especially dry wall, and to make daylight and views more broadly available for workers. This section reviews research on open plan layouts and partitions.

F.2.1 Open Plan Layouts and Partitions

Open plan, dense workspaces present serious challenges for sustainable design. On the positive side, the open plan, flexible, condensed workstation layout reduces the overall use of resources, allows more efficient use of space, reduces surfaces that collect dust, and allows daylight to penetrate deeper into the space. It is also evident that open plan design aids communications and information flow that are so important in many work environments. On the negative side, however, an open plan design increases the potential for distractions and interruptions that may reduce productivity for complex cognitive work, as well as the potential for more rapid transmission of illness. These issues are discussed in more detail below.

Comfort and Satisfaction

Open plan layouts, especially those with low partitions, facilitate access to daylight and views. Workers in open plan spaces that facilitate access to windows are more satisfied overall with lighting and with the work environment (Collins 1975; Heerwagen and Diamond 1991). Open plan workspaces also increase people's awareness, information exchange, and general communication levels (Heerwagen and Hunt 2002). Of the factors that contribute to situation awareness, "visible activity" is considered to be the most important (Gutwin and Greenberg 2001). High visual access aids the ability to see others.

Productivity

Szilagyi and Holland (1980) found that increased workstation density increased satisfaction and information exchange and facilitated tasks for new employees and secretarial staff, but not for managers and for workers with many years of tenure. The researchers suggest that when employees are relatively new, they may be using the surrounding social environment as a source of information and feedback about how to successfully accomplish their jobs. For workers whose tasks are repetitive and cognitively simple, the open plan environment may have positive performance impacts. Researchers hypothesize that the beneficial effects are due to social facilitation that may increase stimulation and effort associated with having their work on view to others (Geen and Gange 1977).

Research has also shown that ready access to others in a work group can aid spontaneous problem solving and information flow and reduce the time to market for some products (Teasley et al. 2000). However, the productivity benefits are clearly related to the specific nature of work and cannot be generalized to all contexts because of the potential for serious increases in distractions and loss of privacy.

F.2.2 Problems with the Open Plan Environment

The benefits of open plan, densely packed workspaces need to be carefully balanced with the potential negative impacts on both psychological factors and physical health. Specifically, research shows the following potential problems:

- **Physical health.** Increased density of workstations and open plan environments increase the overall environmental load of airborne microbials and thus facilitates transmission of illness symptoms (Fisk 2001). Open plan spaces also lead to increased distractions. Distractions often lead to increased psycho-physiological activation indicating that some increased effort is needed to maintain performance (Tafalla and Evans 1997). For complex tasks, the increases in effort may be substantial enough to produce physiological stress.

- **Comfort and satisfaction.** Open plan spaces make it more difficult for workers to have private conversations (Sundstrom et al. 1982). This impedes the ability to develop close work relationships and can also lead to increased feelings of stress and dissatisfaction (Gabarro 1987). There is little evidence that providing small, private booths compensates for the loss of privacy at the workstation.

- **Productivity.** Open plan workspaces increase distractions that are especially detrimental to complex cognitive tasks. Distractions interfere with working memory and analytical thought processes. Distractions are also more of a problem for introverts than for extraverts (Morgenstern et al. 1994; Belojevic et al. 2001). Belojevic et al. found that concentration problems and fatigue were more pronounced for introverts working in noise compared with quiet conditions. Researchers believe these results are due to differences in psycho-physiological activity. Introverts have a more pronounced reaction to noise and this may lead to heightened arousal, which interferes with performance on complex mental processing tasks (Eysenck 1982; Stansfeld and Shine 1993). Furthermore, extroverts regularly select higher noise intensities as optimal, compared with introverts (Geen 1984). These results suggest that design and location of people in settings should take into account these personality differences. Introverts may need to have more enclosure or to be located farther away from sources of distracting noise.